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A study of the viscosities and densities of some multi-component regular non-electrolyte solutions at different temperatures.

Ruo Cai
University of Windsor

A Study of the Viscosities and Densities of Some Binary and Ternary Regular Liquid Mixtures at Different Temperature Levels

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ABSTRACT

The viscosities and densities of ten binary subsystems of the quinary system: heptane, octane, cyclohexane, toluene, and ethylbenzene were measured and reported over the entire composition range at 293.15, 298.15, 308.15, and 313.15 K. In addition, the viscosities and densities of the binary and ternary subsystems of the quinary system: hexane, octane, cyclohexane, toluene, and ethylbenzene were measured and reported at 293.15 and 298.15 K.

The experimental data obtained during the course of the study were employed to test the predictive capabilities of five viscosity models available in the literature; *viz.*, the generalized McAllister model, the pseudo-binary McAllister model, The group contribution GC-UNIMOD model, the generalized corresponding state principle model (GCSP), and the Allan and Teja correlation. These models were selected since they are widely used in the literature.

The results of testing indicated that the generalized McAllister model predicted the experimental data much better than the other models.

DEDICATION

To my parents: to my father who passed away before seeing his dream come true and to my mother who sacrifices without limits. To both of them I will be indebted to the rest of my life.

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CHAPTER 1

INTRODUCTION

1.1 General

Viscosity is a transport property which is defined as the degree to which a fluid resists flow under an applied shearing force. In addition, viscosity is a dynamic property which can be measured in a non-equilibrium experiment and it differs from another property; *viz.*, density which is considered as an equilibrium property and is measured under static conditions (Poling *et al.* 2001).

The dependence of viscosity of liquid mixtures on composition is of paramount importance from practical and theoretical points of view. Practically, the knowledge of viscosity is required in many engineering applications and is essential for the design of fluid flow systems, heat and mass transfer equipment. Theoretically, the dependence of viscosity on composition could provide a better insight into the structure of liquids and the interaction between the molecules in liquid phase. Consequently, in last two decades attention was focused on developing theories and models to describe this dependence. Unfortunately, most of these models were following the "one-size fits all" kind of approach. This resulted in the development of many models which can be reasonable for one class of liquid mixtures, but would be most unreasonable for another class of liquid mixtures.

Our very little knowledge about the structure of liquids hindered progress in developing reliable models for predicting the viscosities of liquid mixtures. This led

Asfour (1980), while studying diffusion in liquid mixtures, to break liquid systems down into three main categories, *viz.*, *n*-alkane mixtures, regular systems, and associated solutions. This approach was selected since it recognizes the different molecular interactions in such different systems. This led to success in tackling the diffusion in liquids problems as evidenced by a series of publications by Asfour and co-workers; e.g., Asfour (1985), Dullien and Asfour (1985), Asfour and Dullien (1986). Upon applying such an approach to the problem of viscosity in liquid mixtures, Asfour and co-workers made a significant progress as evidenced by: Asfour, *et al.* (1991), Wu and Asfour (1992), Wu *et al.* (1988), Nhaesi and Asfour (1998), Nhaesi and Asfour (2000a), Nhaesi and Asfour (2000b) , and Nhaesi, Al-Gherwi, and Asfour (2005).

The viscosity models for liquid systems currently available in the literature can be classified into two main categories; *viz.*, correlative and predictive models. The correlative models require experimental data in order to obtain the values of the adjustable parameters contained in such models. The predictive models only require the knowledge of the pure compounds properties and their molecular parameters in order to estimate the viscosities of the liquid mixture(s) of interest.

In the present work, five models were selected for testing by using the data generated in this investigation. The models are: (i) the generalized McAllister three-body interaction model, (ii) the pseudo-binary McAllister model, (iii) the group contribution GC-UNIMOD model, (iv) the generalized corresponding states principle GCSP, and (v) the Allan and Teja correlation. All the preceding models are predictive in nature except the Allan and Teja correlation which is correlative. The preceding models were tested and

their predictive capabilities were compared by utilizing the experimental data obtained during the course of this study.

The generalized McAllister three-body model and the pseudo-binary McAllister model are predictive versions of the original McAllister model which was developed and reported by McAllister (1960). The McAllister model was developed for correlating the viscosities of binary liquid mixtures. It was based on Eyring's absolute rate theory. The McAllister model was considered the best correlating method for binary liquid systems (Reid *et al.* 1977). The model was extended to ternary liquid systems by Chandramouli and Laddha (1963). The major drawback of the McAllister model is the fact that it contains adjustable parameters which in turn require costly and time consuming experimental data to determine. To overcome this problem, Asfour *et al.* (1991) reported a novel technique for predicting the McAllister model parameters for binary liquid *n*-alkane systems by employing the viscosities of the pure components and the molecular parameters of the components constituting a liquid mixture. Thus, in essence, Asfour *et al.* (1991) converted the McAllister model from a purely correlative to a purely predictive model. Later Nhaesi and Asfour developed, in series of publications, the predictive form of the McAllister model into an expression that is capable of successfully predicting the viscosities of regular solutions (Nhaesi and Asfour 1998). Following that, Nhaesi and Asfour reported a form of the model that is capable of predicting the viscosities of multi-component liquid *n*-alkane and regular solutions mixtures (Nhaesi and Asfour 2000a). Moreover, Nhaesi and Asfour (2000b) incorporated the "*pseudo-binary*" model, which was developed and reported earlier by Wu and Asfour (1992), into the Generalized McAllister model which was developed and reported by Nhaesi and Asfour (2000a). The

resulting model showed excellent predictive capability. In addition, the incorporation of the pseudo-binary model resulted in reducing the number of adjustable parameters to two no matter how many components were involved in constituting the multi-component mixture investigated. This obviously reduces the complexity and time required for viscosity calculation.

The GC-UNIMOD proposed by Cao *et al.* (1992, 1993a, 1993b) is a group contribution technique used to predict the viscosity of multi-component liquid mixtures. The model assumes that the interaction between the molecules in the system is equivalent to interaction between the groups constituting each molecule. This makes the method approximate since it is not necessary that the contribution of a particular group in a molecule is the same as for the same group in different molecule. Furthermore, the model was developed for predicting both the viscosity of liquid mixtures and for the vapor-liquid equilibria for any type of compounds. While this may appear to be an advantage, it in fact sacrifices the method's accuracy.

The Generalized Corresponding States Principle (GCSP) was developed by Teja and Rice (1981) by analogy to the well-known corresponding states principle used in thermodynamics. The model was used to estimate the viscosities of multi-component liquid mixtures. When the mixture is composed of more than two components, an appropriate choice of two reference fluids is required. No rule was provided by those authors for the selection of the reference fluids. This represented one of the major weaknesses of their method since the predictive capability of the method was highly dependent on the choice of the reference fluids.

Asfour and Wu (1992) modified and hence improved the performance of the GCSP by introducing the "pseudo-binary" model which helped to overcome the problem of the selection of the two reference fluids, which was the major drawback of the GCSP. The method was called by Wu and Asfour (1992), the Modified Generalized Corresponding States Principle (MGCSP). The use of the MGCSP method was restricted to *n*-alkanes liquid mixtures.

1.2 Objectives

The present work has the following objectives:

(i) Experimentally measuring and reporting the viscosities and densities of ten binary sub-systems of the quinary system heptane, octane, cyclohexane, toluene, and ethylbenzene over the entire composition range at 293.15, 298.15, 308.15, and 313.15 K. The experimental data on the quinary system and its quaternary and ternary subsystems were reported earlier by co-workers El-Hadad (2004) and Cai (2004) over the same temperature range. In addition, the viscosities and densities of the binary and ternary subsystems of the quinary system; hexane, octane, cyclohexane, toluene, and ethylbenzene at 293.15 and 298.15 K were measured. The viscosities and densities of the quinary system; hexane, octane, cyclohexane, toluene, and ethylbenzene and its quaternary subsystems were reported earlier by co-workers El-Hadad (2004) and Ruo (2004).

(ii) Employing the experimental data obtained in this study to critically test some of the models available in the literature and comparing their predictive capabilities.

1.3 Contributions and Significance

Data are required for their own value as well as for subjecting models to critical testing. We are the only laboratory in the world that reports viscosity and density data on quinary liquid systems. Data on quaternary systems range from very scarce to non-existent in the literature. As indicated earlier, the data on the selected quinary and quaternary subsystems have not been reported earlier in the literature. Consequently, we were motivated to complete the sets of data of those quinary and quaternary subsystems by measuring their binary and ternary subsystems. In addition, the high reliability and accuracy of our data will make them valuable additions to the literature. Moreover, by employing these data for critically testing viscosity models permitted us to reach important conclusions which we will report in detail in this thesis.

CHAPTER 2

LITERATURE SURVEY

2.1 General

Viscosity is a very important property in many engineering applications such as fluid flow systems, heat transfer equipment, and mass transfer and separation processes. In the last century a great deal of research has been conducted to study the dependence of viscosity of liquid mixtures on composition. Many models have been developed for correlating and/or predicting the viscosity of liquid mixtures. Generally, the viscosity predictive models can be classified, according to Mehrotra *et al.* (1996), into two types; namely, empirical models and semi-theoretical models. The empirical models are strictly based on experimental data whereas the semi-theoretical models were developed on the basis of one or more theory, but they require experimental data in order to determine the adjustable parameter(s) contained in such models.

In the present study, five models were selected, *viz.*; the predictive version of the McAllister model, the pseudo-binary McAllister model, the group-contribution method (GC-UNIMOD), the generalized corresponding states principle, and the Allan and Teja correlation. According to the classification of models indicated earlier, the first four models are considered to be semi-theoretical whereas the last one is empirical. Discussion of the foregoing models is in order.

2.2 The Semi-Theoretical Models for Predicting the Viscosity of Liquid Mixtures.

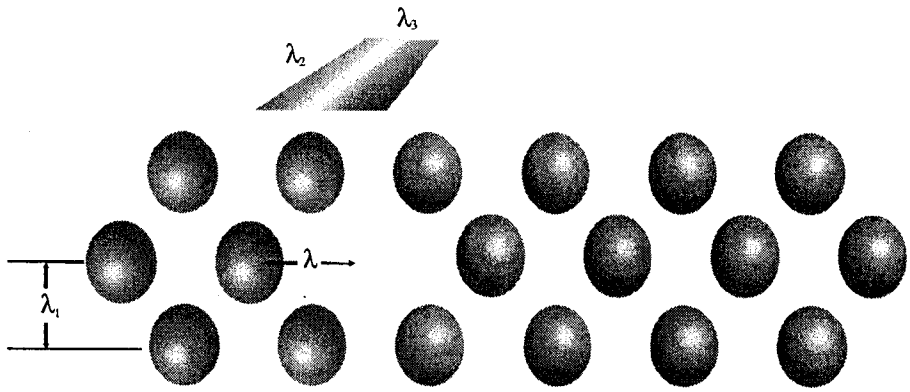
2.2.1 The McAllister's model

(i) Reaction rate theory

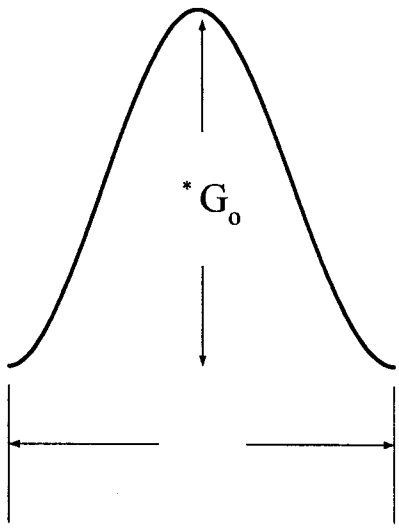
Assuming that viscous flow is a rate process, Eyring and coworkers (Eyring, 1936; Ewell and Eyring, 1937) developed one of the most well-known molecular theories of the viscosity of liquids.

The theory is based on the assumption that every molecule is confined within a cage formed by other molecules surrounding it. If one envisages two liquid layers separated by a distance λ_1,, and if a shear force is applied to one of those layers, a molecule "jumps" or escapes from its cage to another available vacant site "hole" by crossing a potential energy barrier. Such a situation is depicted in Figure 2.1(a). The average area available to the molecule is $\lambda_2\lambda_3$. At rest when there is no force acting on the liquid, the liquid rearranges where one molecule jumps from its site into another one due to thermal activation and the rates of jumping to the left and to the right are assumed to be equal so that there is no net flow. As indicated earlier, in order for a molecule to jump to a hole it has to cross over a potential energy barrier ΔG_0 as indicated in Figure 2.1(b). The frequency for both forward and backward jumps is given by:

$$r_0 = \frac{kT}{h}\exp\left(-\frac{\Delta G_0}{KT}\right) \qquad (2.1)$$



(a)



(b)

space

Figure 2.1: The Eyring Molecular Model of Liquid Viscosity

where k is Boltzmann's constant, h is Planck's constant, and T is absolute temperature.

Now, if a shear stress of magnitude f is applied forward to the liquid, the resulting force acting on the molecule is $f\lambda_2\lambda_3$. It is assumed that the only mechanical work created is consumed to deliver the molecule to the top of the energy barrier. It is also assumed that the molecule gives up its energy as heat on the other side of the energy barrier. From the aforementioned assumption, the work done is:

$$\text{Work} = f\lambda_1\lambda_2\left(\frac{\lambda}{2}\right) \tag{2.2}$$

where λ is the distance between the molecules. The potential energy barrier in case of viscous flow differs from the non-flow (rest) situation and therefore the forward rate of a molecule jumping is

$$r_{\text{forward}} = \left(\frac{kT}{h}\right)\exp\left(-\frac{\Delta G_0 - f\lambda_1\lambda_2\frac{\lambda}{2}}{KT}\right) \tag{2.3}$$

and the backward rate of jumping is

$$r_{\text{backword}} = \left(\frac{kT}{h}\right)\exp\left(-\frac{\Delta G_0 + f\lambda_1\lambda_2\frac{\lambda}{2}}{KT}\right) \tag{2.4}$$

therefore, the net rate of jumping is

$$r_{\text{net}} = \left(\frac{kT}{h}\right)\exp\left(-\frac{\Delta G_0}{KT}\right)\left[\exp\left(\frac{f\lambda_2\lambda_3\lambda}{2KT}\right) - \exp\left(-\frac{f\lambda_2\lambda_3\lambda}{2KT}\right)\right] \tag{2.4}$$

With simplifications, the above equation becomes

$$r_{net} = \left(\frac{kT}{h}\right)\exp\left(-\frac{\Delta G_0}{KT}\right)\left[\exp\left(2\frac{f\lambda_2\lambda_3\lambda}{2KT}\right)\right] = \left(\frac{f\lambda_2\lambda_3\lambda}{h}\right)\exp\left(-\frac{\Delta G_0}{KT}\right) \qquad (2.5)$$

The velocity gradient across the two molecular layers separated by a distance λ_1 is

$$\text{Velocity Gradient} = \frac{\text{Velocity Difference}}{\lambda_1}$$

$$\text{Velocity Gradient} = \frac{\text{distance per jump} \times \text{number of jumps per second}}{\lambda_1}$$

$$\text{Velocity Gradient} = \frac{\lambda r}{\lambda_1} \qquad (2.6)$$

Since the viscosity η is defined as

$$\eta = \frac{\text{Shear Stress}}{\text{Velocity Gradient}} \qquad (2.7)$$

Substituting equation (2.6) into equation (2.7)

$$\eta = \frac{f\lambda_1}{\lambda r} \qquad (2.8)$$

By substituting equation (2.5) into equation (2.8) yields

$$\eta = \frac{h\lambda_1}{\lambda_2\lambda_3\lambda^2}\exp\left(\frac{\Delta G_0}{KT}\right) \qquad (2.9)$$

Postulating that $\lambda_1 \approx \lambda$ and considering $\lambda_1\lambda_2\lambda_3$ as the effective volume occupied by a molecule V_0, equation (2.9) becomes

$$\eta = \frac{h}{V_0} \exp\left(\frac{\Delta^* G_0}{KT}\right) \tag{2.10}$$

Equation (2.10) may also be written as

$$\eta = \frac{hN}{V_m} \exp\left(\frac{\Delta^* G}{KT}\right) \tag{2.11}$$

where N is Avogadro's number, V_m is the molar volume of the liquid, and Δ^*G is the molar activation energy of viscous flow.

(ii) McAllister's model

McAllister (1960) proposed a viscosity model for binary liquid mixtures, on the basis of Eyring's theory, and used the following form of equation (2.11) for the kinematic viscosity

$$\nu = \frac{hN}{M} \exp\left(\frac{\Delta^* G}{KT}\right) \tag{2.12}$$

For a binary mixture that contains two types of molecules, type 1 and type 2, when a molecule of type 1 crosses the energy barrier, it may interact with molecule of type 1, type 2, or both of them together, depending on the local composition. The interaction can either be assumed to be a three-body or four-body type. The three-body interaction is simpler than the four-body interaction. According to McAllister, this assumption is valid unless the difference in size between the two types of molecules is large and in this case a four-body type is more likely to describe the situation.

Figure 2.2 illustrates the three-body type interaction with the six possible interactions; 1-1-1, 2-2-2, 1-2-1, 2-1-2, 1-1-2, and 1-2-2.

With the assumption that the free energy of activation of flow is additive and that the probability of interactions is proportional to the mole fractions of the involved species, the free energy of activation of the mixture can generally be given by

$$\Delta^*G = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} x_i x_j x_k \Delta^*G_{ijk} \tag{2.13}$$

where X is the mole fraction. For simplicity, the following equations were assumed

$$\Delta^*G_{121} = \Delta^*G_{112} = \Delta^*G_{12} \tag{2.14}$$

$$\Delta^*G_{212} = \Delta^*G_{122} = \Delta^*G_{21} \tag{2.15}$$

Expanding equation (2.13) and utilizing equations (2.14) and (2.15) yields

$$\Delta^*G = x_1^3\Delta^*G_1 + 3x_1^2X_2\Delta^*G_{12} + 3x_1x_2^2\Delta^*G_{21} + x_2^3\Delta^*G_2 \tag{2.16}$$

Equation (2.16) indicates that each type of energy of activation is related to its corresponding kinematic viscosity as in equation (2.12).

For the mixture

$$\nu = \left(\frac{hN}{M_m}\right)e^{\Delta^*G/RT} \tag{2.17}$$

where

$$M_m = \sum_i x_i M_i \tag{2.18}$$

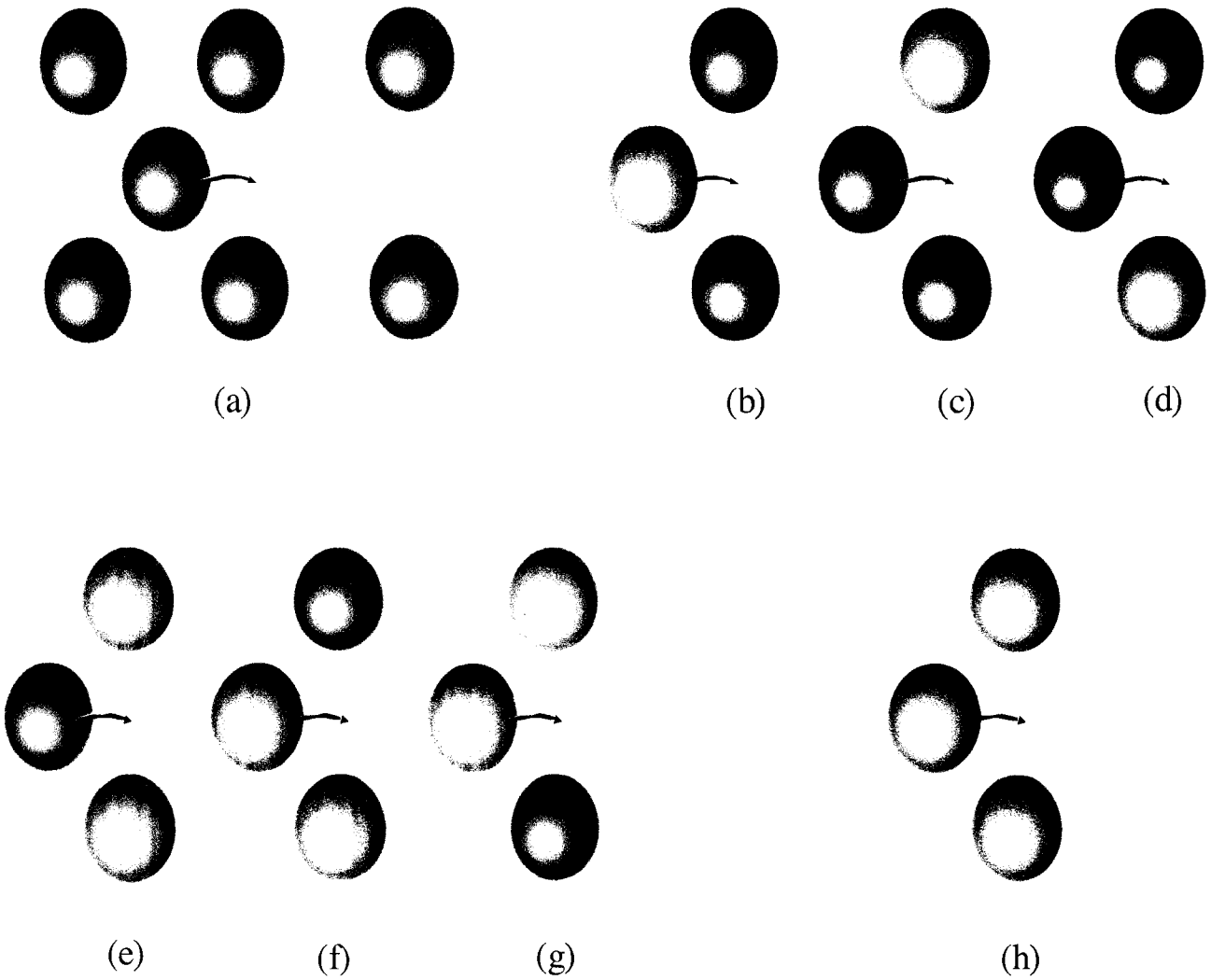


Figure 2.2: Types of Viscosity Interactions in a Binary Mixtures, Three-Body interaction Model

For pure component i

$$\nu_i = \left(\frac{hN}{M_i}\right) e^{\Delta^* G_i / RT} \tag{2.19}$$

and for interactions

$$\nu_{ij} = \left(\frac{hN}{M_{ij}}\right) e^{\Delta^* G_{ij} / RT} \tag{2.20}$$

where

$$M_{ij} = (2M_i + M_j)/3 \tag{2.21}$$

Substituting equation (2.16) into (2.17) yields

$$\nu = \left(\frac{hN}{M_m}\right) e^{\left(x_1^3 \Delta^* G_1 + 3x_1^2 x_2 \Delta^* G_{12} + 3x_1 x_2^2 \Delta^* G_{21} + x_2^3 \Delta^* G_2\right)/RT} \tag{2.22}$$

when equations (2.19) and (2.20) are substituted into equation (2.22) and upon rearrangement, the following McAllister three-body model is obtained:

$$\begin{aligned} \ell n\nu = {} & x_1^3 \ell n\nu_1 + 3x_1^2 x_2 \ell n\nu_{12} + 3x_1 x_2^2 \ell n\nu_{21} + x_2^3 \ell n\nu_2 - \ell n[x_1 + x_2 M_2/M_1] + \\ & 3x_1^2 x_2 \ell n[(2 + M_2/M_1)/3] + 3x_1 x_2^2 \ell n[(1 + 2M_2/M_1)/3] + x_2^3 \ell n[M_2/M_1] \end{aligned} \tag{2.23}$$

McAllister's model, equation (2.23), contains two adjustable parameters; *viz.*, ν_{12} and ν_{21}. These parameters have to be determined by fitting equation (2.23) to viscosity-composition experimental data. In addition, it should be pointed out that equation (2.23) is a cubic equation and therefore it could have a maximum, a minimum, neither or both. As it was reported by McAllister, equation (2.23) performs well when the molecular diameter ratio of the components is less than 1.5.

In a similar manner, McAllister developed and reported a four-body interaction model that is employed when the size of one component is much larger than that of the

other component. The possible interactions are illustrated in Figure 2.3. The four-body interaction model is a quartic equation which is given by

$$\begin{aligned}\ell n\nu = {} & x_1^4 \ell n\nu_1 + a x_1^3 x_2 \ell n\nu_{1112} + 6 x_1^2 x_2^2 \ell n\nu_{1122} \\ & + 4 x_1 x_2^3 \ell n\nu_{2221} + x_2^4 \ell n\nu_2 - \ell n\left(x_1 + x_2 \frac{M_2}{M_1} \right) \\ & + 4 x_1^3 x_2 \ell n\left(\frac{3 + M_2/M_1}{4} \right) + 6 x_1^2 x_2^2 \ell n\left(\frac{1 + M_2/M_1}{2} \right) \\ & + 4 x_1 x_2^3 \ell n\left(\frac{1 + 3M_2/M_1}{4} \right) + x_2^4 \ell n\left(M_2/M_1 \right)\end{aligned} \tag{2.24}$$

The above equation contains three adjustable parameters. The values of the parameters can be determined by fitting equation (2.24) to experimental data by using the least-squares technique. The major drawback of McAllister's model is the presence of the adjustable parameters which require costly and time consuming experimental data for their determination.

(iii) <u>Extending the McAllister model to ternary systems</u>

Chandramouli and Laddha (1963) extended the McAllister's three-body model to ternary liquid systems. In this extended form, a ternary interaction parameter was included in addition to the binary interaction parameters. Kalidas and Laddha (1964) validated the model with experimental data on ternary liquid systems and concluded that the extended McAllister's model for ternary mixtures properly fitted experimental data.

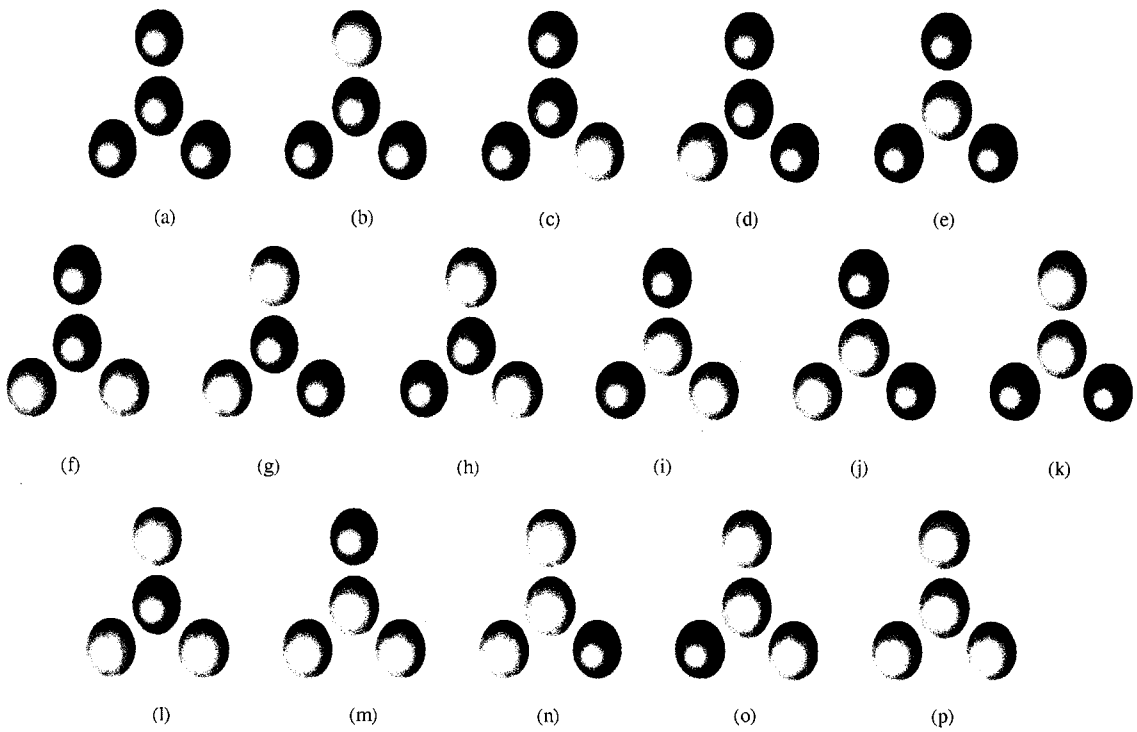


Figure 2.3: Types of Viscosity Interactions in a Binary Mixtures, Four-Body interaction Model

The extended form of McAllister's model is given by

$$\begin{aligned}\ell n\nu = {} & x_1^3\ell n\nu_1 + x_2^3\ell n\nu_2 + x_3^3\ell n\nu_3 + 3x_1^2x_2\ell n\nu_{12} + 3x_1^2x_3\ell n\nu_{13} + 3x_2^2x_1\ell n\nu_{21} \\ & + 3x_2^2x_3\ell n\nu_{23} + 3x_3^2x_1\ell n\nu_{31} + 3x_3^2x_2\ell n\nu_{32} + 6x_1x_2x_3\ell n\nu_{123} \\ & - \ell n(x_1M_1 + x_2M_2 + x_3M_3) + x_1^3\ell nM_1 + x_2^3\ell nM_2 + x_3^3\ell nM_3 \\ & + 3x_1^2x_2\ell n\left(\frac{2M_1 + M_2}{3}\right) + 3x_1^2x_3\ell n\left(\frac{2M_1 + M_3}{3}\right) \\ & + 3x_2^2x_1\ell n\left(\frac{2M_2 + M_2}{3}\right) + 3x_2^2x_3\ell n\left(\frac{2M_2 + M_3}{3}\right) \\ & + 3x_3^2x_1\ell n\left(\frac{2M_3 + M_1}{3}\right) + 3x_3^2x_2\ell n\left(\frac{2M_3 + M_2}{3}\right) \\ & + 6x_1x_2x_3\ell n\left(\frac{M_1 + M_2 + M_3}{3}\right) \end{aligned} \tag{2.25}$$

where ν_{12}, ν_{21}, ν_{13}, ν_{31}, ν_{23}, ν_{32} are six interaction parameters and ν_{123} is the ternary interaction parameter.

(iv) Conversion of the McAllister model into a predictive model

After about three decades since McAllister developed his model, Asfour and coworkers could successfully, for the first time, convert the McAllister model from a correlative model into a predictive technique. They later extended it so that it could predict the viscosities of multi-component systems (Asfour *et al.* 1991, Nhaesi and Asfour 1998, Nhaesi and Asfour 2000a, Nhaesi and Asfour 2000b). Detailed presentation of the work of Asfour and co-workers is in order.

(a) *n*-alkane binary liquid systems (Asfour *et al.* 1991)

Asfour *et al.* (1991) proposed a technique for predicting the values of the McAllister model parameters for binary *n*-alkane liquid mixtures from pure component viscosities and molecular parameters. Asfour *et al.* (1991) plotted the lumped parameter, $\nu_{12}/(\nu_1^2\nu_2)^{1/3}$ versus the reciprocal of absolute temperature (1/T). They found such plots consisted of horizontal lines as shown in Figure2.4. On that basis they concluded that the lumped parameter is independent of temperature. They then plotted the lumped parameter $\nu_{12}/(\nu_1^2\nu_2)^{1/3}$ versus $\left[(N_2-N_1)^2/(N_1^2N_2)^{1/3}\right]$, where N_1 and N_2 are the carbon numbers of components 1 and 2, respectively. A straight line was obtained, as shown in Figure 2.5. Asfour *et al.* (1991) reported the following equation as a fit to the straight line they had obtained

$$\frac{\nu_{12}}{(\nu_1^2\nu_2)^{1/3}} = 1 + 0.044\frac{(N_2-N_1)^2}{(N_1^2N_2)^{1/3}} \tag{2.26}$$

Therefore, equation (2.26) can be employed for the calculation of the McAllister model adjustable parameter ν_{12}. Asfour *et al.* (1991) also showed that the other McAllister model binary adjustable parameter, ν_{21}, can be calculated with the help of following equation:

$$\nu_{21} = \nu_{12}\left(\frac{\nu_2}{\nu_1}\right)^{1/3} \tag{2.27}$$

where ν_{12} is the binary interaction parameter calculated by equation (2.26) and ν_1 and ν_2 are the kinematic viscosities of components 1 and 2, respectively.

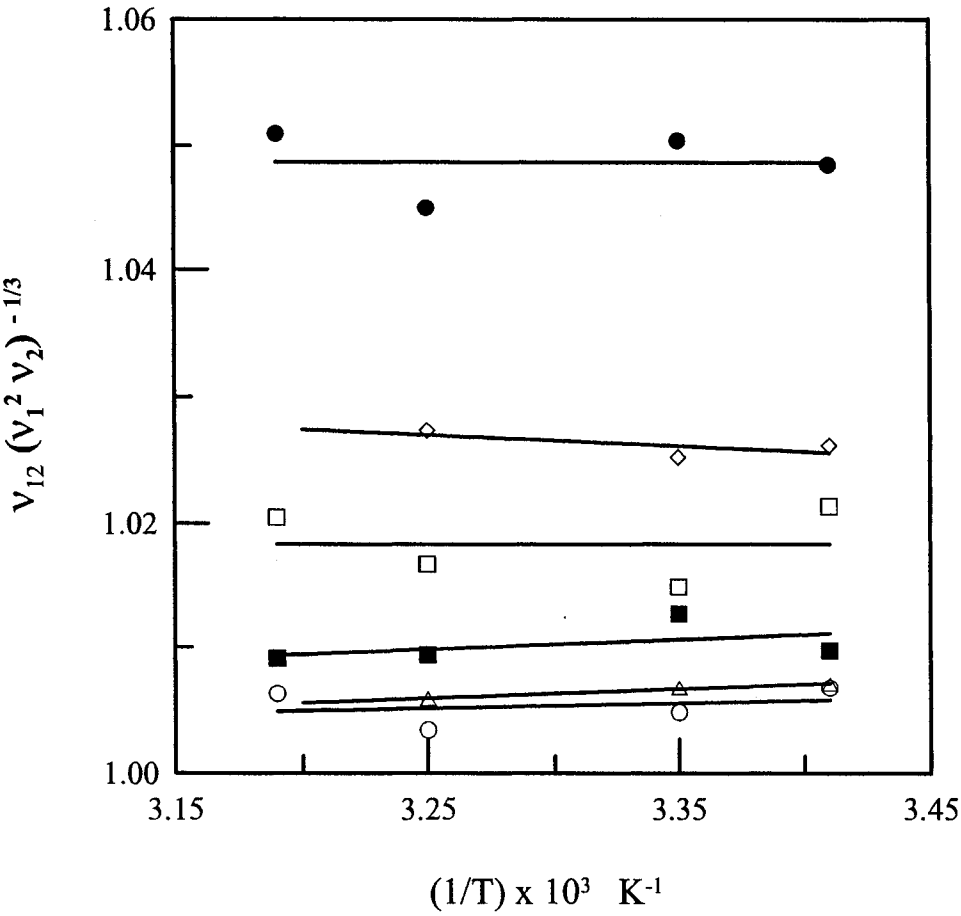


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Figure 2.4: Variation of the Lumped Parameter $v_{12}/(v_1^2 v_2)^{1/3}$ with 1/T for n-alkane systems for which $|N_2 - N_1| \leq 3$ (Data taken from Cooper, 1988)

Legend

- △ Hexane (A) - Heptane (B)
- ◇ Hexane (A) - Octane (B)
- ○ Heptane (A) - Octane (B)
- ● Heptane (A) - Decane (B)
- ■ Tetradecane (A) - Hexadecane (B)
- □ Octane (A) - Decane (B)

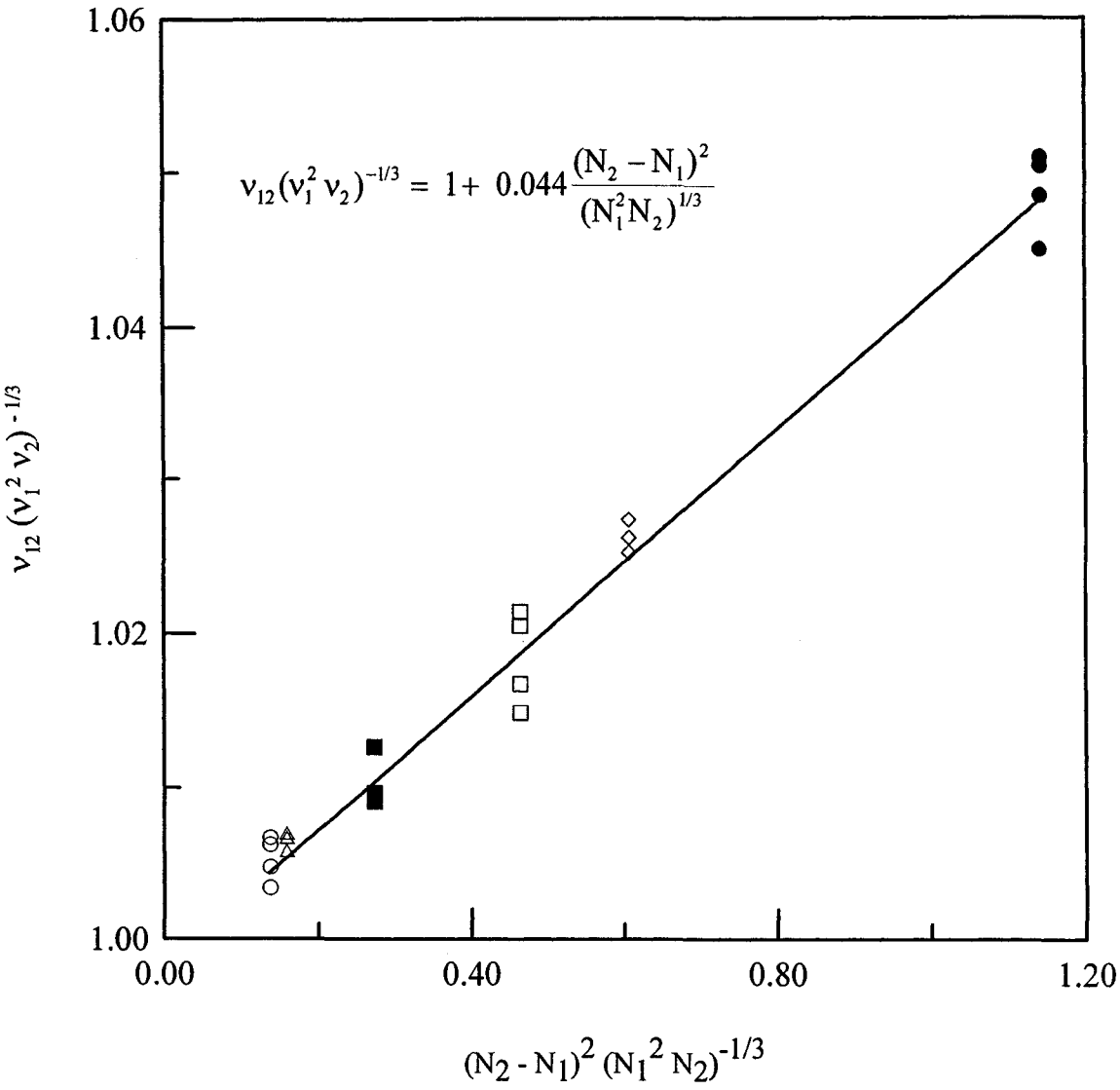

Figure2.5: Variation of the Lumped Parameter $\nu_{12}/\left(\nu_1^2\nu_2\right)^{1/3}$ with $\left[(N_2 - N_1)^2/\left(N_1^2 N_2\right)^{1/3}\right]$

(Legends as those in Figure 2.4)

Asfour *et al.* (1991) indicated that when the difference between the carbon numbers of the two components in a binary mixture is equal to or larger than 4, the McAllister four-body model should be employed for better results. Therefore, with a similar treatment, they developed the following equations for the prediction of the McAllister four-body model when $|N_2 - N_1| \geq 4$

$$\frac{\nu_{1122}}{(\nu_1^2 \nu_2)^{1/3}} = 1 + 0.03 \frac{(N_2 - N_1)^2}{(N_1^2 N_2)^{1/3}} \tag{2.28}$$

$$\nu_{1112} = \nu_{1122} \left(\frac{\nu_2}{\nu_1} \right)^{1/3} \tag{2.29}$$

$$\nu_{2221} = \nu_{1122} \left(\frac{\nu_2}{\nu_1} \right)^{1/3} \tag{2.30}$$

Asfour *et al.* (1991) used data on binary liquid *n*-alkane systems at different temperatures to test their technique. The results they obtained showed that viscosity prediction using their developed technique was far superior to any other model.

(b) Regular binary liquid systems

Nhaesi and Asfour (1998) extended the Asfour *et al.* (1991) technique to regular binary liquid solutions. Nhaesi and Asfour (1998) reported a technique to calculate the "*effective carbon numbers*" of compounds other than *n*-alkanes. They prepared a semi-log plot of the kinematic viscosities of pure liquid *n*-alkane (C_5 to C_{18}) hydrocarbons at 308.15 K against their carbon numbers. This resulted in the straight line relationship depicted in Figure 2.6. The line is represented by the following equation:

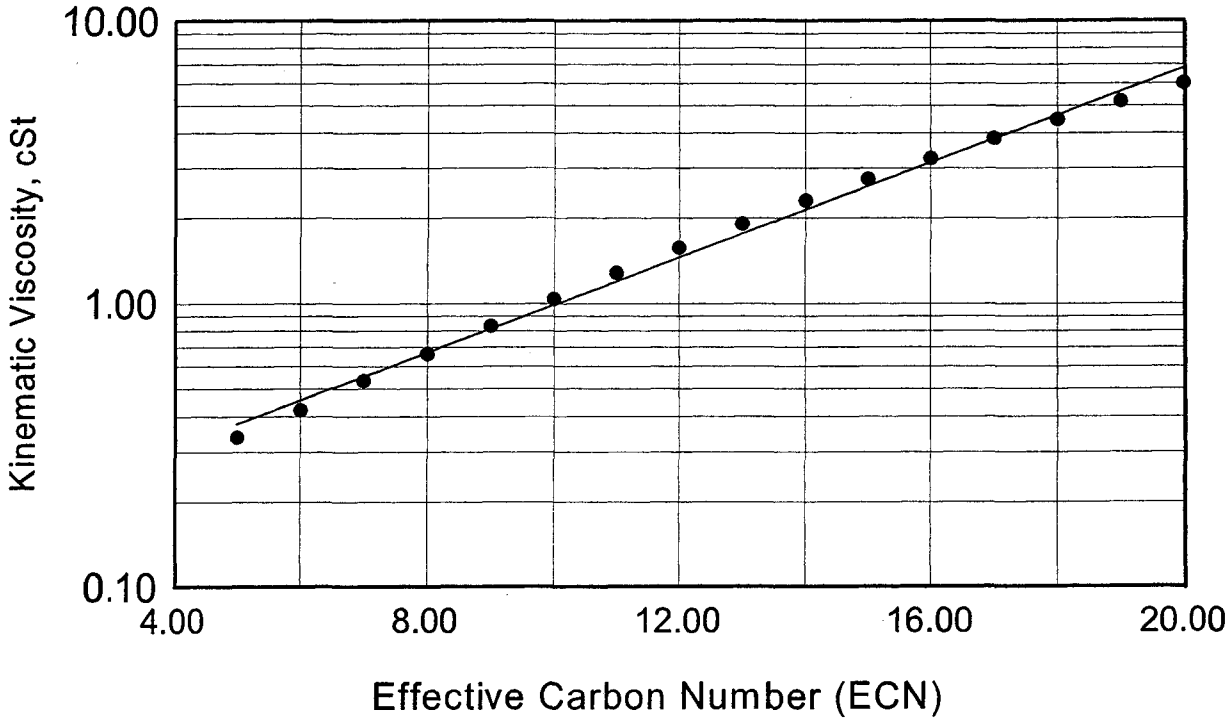

Figure 2.6: Experimental kinematic viscosity for *n*-alkanes versus the effective carbon number

$$\ell n(\nu) = A + B(N) \tag{2.31}$$

where A = -1.943 and B = 0.193, and ν in cSt.

Using equation (2.31), Nhaesi and Asfour (1998) indicated that the effective carbon number (ECN) of any regular compound can be calculated when its kinematic viscosity at 308.15 K is substituted. This allowed them to develop an equation similar to the equation they had developed earlier for *n*-alkane systems. The equation is given by

$$\frac{\nu_{12}}{\left(\nu_1^2\nu_2\right)^{1/3}} = 0.8735 + 0.0715\frac{\left(ECN_2 - ECN_1\right)^2}{\left(ECN_1^2 ECN_2\right)^{1/3}} \tag{2.32}$$

Again, equation (2.27) is used to calculate the parameter ν_{21}.

(c) The *pseudo-binary* McAllister model

Nhaesi and Asfour (2000a) used the *pseudo-binary* concept developed earlier by Wu and Asfour (1992) to extend the predictive McAllister model to multi-component *n*-alkanes and regular systems. The advantage of using the *pseudo-binary* model is that it reduces the number of parameters to only two regardless of the number of the components included in a multi-component system. This obviously dramatically reduces the complexity and time required for calculations.

The carbon number in case of *n*-alkane systems and the *effective carbon number* in case of regular solutions for the *pseudo*-component can be estimated from the following mixing rule suggested by Nhaesi and Asfour (2000a).

$$(ECN)_{2'} = \sum_{i=2}^{n} X_i (ECN)_i \tag{2.33}$$

where n is the total number of components in the mixture.

The viscosity of the *pseudo*-component is calculated from the following equation

$$\ell n \nu_{2'} = \sum_{i=2}^{n} X_i \ell n \nu_i \tag{2.34}$$

And the molecular weight of the pseudo-component is estimated from the following mixing rule

$$\ell n M_{2'} = \sum_{i=2}^{n} X_i \ell n M_i \tag{2.35}$$

The mole fraction X_i used in equations (2.33), (2.34), and (2.35) is normalized by mean of the following formula

$$X_i = \frac{x_i}{\sum_{i=2}^{n} x_i} \tag{2.36}$$

Nhaesi and Asfour (2000a) reported that once the $(ECN)_{2'}$ and the $\nu_{2'}$ are obtained, they can be substituted in equations (2.28) for ***n***-alkane systems, and equation (2.32) for regular solutions. Equation (2.27) is then used to obtain the McAllister binary interaction parameter, ν_{21}. Consequently, the obtained parameters are substituted along with $M_{2'}$ into equation (2.23), which is the McAllister three-body model for binary systems. This yields the predicted value of the kinematic viscosity of the liquid mixture. In this method, there are only two interaction parameters to be estimated, no matter how many components are in the mixture.

Nhaesi and Asfour (2000a) applied their proposed model to predict the viscosities of some multi-component *n*-alkane and regular liquid systems and compared the obtained results with those of some other predictive models. On the basis of the results of tests

conducted by Nhaesi and Asfour (2000a), they indicated that the *pseudo-binary* McAllister model performed better than other literature models.

(d) The generalized McAllister three-body model

Nhaesi and Asfour (2000b) reported a generalized McAllister three-body interaction model for multi-component liquid mixtures. In addition, they also reported a technique for predicting the ternary interaction parameter of McAllister's model. The generalized model allows the user to predict the viscosity data of liquid mixtures of any number of components from only pure compounds information.

Assuming three-body interactions and that the free energies of activation for viscous flow are additive, Nhaesi and Asfour (2000b) based their derivation on the following expression for the activation energy of a multi-component system

$$\Delta G_m = \sum_{i=1}^{n} x_i^3 \Delta G_i + 3\sum_{i=1}^{n}\sum_{j=1}^{n} x_i^2 x_j \Delta G_{ij} + 6\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n} x_i x_j x_k \Delta G_{ijk} \qquad (2.37)$$

where n is the number of components in the mixture.

Moreover, the following assumptions were also made for simplification

$$\Delta G_{iji} = \Delta G_{iij} = \Delta G_{ij} \qquad (2.38)$$

$$\Delta G_{jij} = \Delta G_{ijj} = \Delta G_{ji} \qquad (2.39)$$

The Arrhenius-type equation for each type of activation energy employed in equation (2.37) were postulated as follows

$$\nu_m = \frac{hN}{M_{avg}} e^{(\Delta G_m / RT)} \qquad (2.40)$$

where M_{avg} is represented by the following formula

$$M_{avg} = \sum_{i=1}^{n} x_i M_i \tag{2.41}$$

For pure component i

$$v_i = \frac{hN}{M_i} e^{(\Delta G_i / RT)} \tag{2.42}$$

For the binary interactions

$$v_{ij} = \frac{hN}{M_{ij}} e^{(\Delta G_{ij} / RT)} \tag{2.43}$$

where

$$M_{ij} = (2M_i + M_j)/3 \tag{2.44}$$

For the ternary interactions

$$v_{ijk} = \frac{hN}{M_{ijk}} e^{(\Delta G_{ijk} / RT)} \tag{2.45}$$

where

$$M_{ijk} = (M_i + M_j + M_k)/3 \tag{2.46}$$

Taking the logarithms of equations (2.40), (2.42), (2.43) and (2.45), and substituting them into equation (2.37) to eliminate the free energies of activation and rearranging, Nhaesi and Asfour (2000b) developed the following form of the McAllister's three-body model for multi-component liquid mixtures

$$\begin{aligned} \ell n v_m = & \sum_{i=1}^{n} x_i^3 \ell n(v_i M_i) + 3 \sum_{\substack{i=1 \\ i \neq j}}^{n} \sum_{j=1}^{n} x_i^2 x_j \ell n(v_{ij} M_{ij}) \\ & + 6 \sum_{\substack{i=1 \\ i \neq j \neq k}}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} x_i^2 x_j x_k \ell n(v_{ijk} M_{ijk}) - \ell n(M_{avg}) \end{aligned} \tag{2.47}$$

As can be observed from equation (2.47), only the binary and ternary interaction parameters are needed. In order to estimate how many binary and ternary parameters are needed for a particular n-component mixture, Nhaesi and Asfour (2000b) suggested the following formula for the number of the binary interaction parameters

$$N_2 = \frac{n!}{(n-2)!} \tag{2.48}$$

and the following one for the number of ternary interaction parameters

$$N_3 = \frac{n!}{3!(n-3)!} \tag{2.49}$$

The binary interaction parameters can be calculated by using the techniques discussed earlier. In case of regular systems, equation (2.31) is used to calculate the effective carbon numbers. For the ternary interaction parameters, Nhaesi and Asfour (2000b) developed a similar technique and obtained the following equation for the prediction of the ternary interaction parameters

$$\frac{v_{ijk}}{(v_i v_j v_k)^{1/3}} = 0.9637 + 0.0313 \frac{(N_k - N_i)^2}{N_j} \tag{2.50}$$

Again, in case of regular systems one can use equation (2.31) to estimate the effective carbon numbers.

Consequently, Nhaesi and Asfour (2000b) not only extended the McAllister model to multi-component mixtures but also converted the model into a predictive

technique where only pure components' kinematic viscosities and their molecular parameters are required. Nhaesi and Asfour (2000b) employed an extensive database to test their method and compared the results they had obtained with those of some other literature models. Their reported results indicated that their method was far superior than other literature models.

(e) McAllister three-body model with the group contribution method (Nhaesi *et al.* 2005)

In a very recent publication, Nhaesi *et al.* (2005) proposed a novel technique that employed the principles of the group contribution method for the prediction of the McAllister model interaction parameters for binary and multi-component liquid *n*-alkane systems. They calculated the contributions of the CH_2 and the CH_3 groups and utilized those contributions to predict the viscosities of binary and ternary interaction parameters of McAllister model. They used an extensive viscosity database for binary, ternary, quaternary, and quinary *n*-alkane mixtures to test the model and compare its predictive capability with some other literature models. The results showed that the proposed technique predicted the data better than the other techniques. Such a pioneering approach provides a reliable tool for not only predicting the viscosities of defined hydrocarbon systems, but also would provide a very promising method for predicting the viscosities of undefined hydrocarbon mixtures.

2.2.2 The GC-UNIMOD model (The Group Contribution Approach)

Cao *et al.* (1992) reported a viscosity model for multi-component liquid systems based on the Eyring rate process theory combined with statistical thermodynamics and local composition. The model is given by the following equation

$$\ell n(vM) = \sum_{i=1}^{n} x_i \ell n(v_i M_i) - \sum_{i=1}^{n} q_i n_i x_i \sum_{j=1}^{n} \theta_{ij} \ell n(\tau_{ij}) \qquad (2.51)$$

where q_i is the area parameter of molecule i, θ_{ij} is the local composition, τ_{ij} is the interaction parameter, and n_i is a pure component parameter and given by the following relation

$$\ell n(n_i) = \sum_{j=0} A_j T^j \qquad (2.52)$$

The values of the Aj's in equation (2.52) were obtained by correlating the experimental viscosities of 314 pure compounds.

As indicated by Cao *et al.* (1992), their model is correlative. In the case of binary liquid systems there are two interaction parameters, τ_{12} and τ_{21}, which have to be determined from fitting equation (2.51) to experimental data of binary liquid mixtures. However, their technique could be predictive when it is applied to systems other than binary systems and the binary interaction parameters are determined from pure compounds and binary systems data. They employed their model to predict the viscosity of 15 different multi-component mixtures and compared the resulting overall percent absolute average deviation (%AAD) to that obtained from utilizing the method developed

by Wu (1986) by using the same data. The Cao *et al.* (1992) method resulted in an overall %AAD of 2.9% whereas the Wu (1986) method showed an overall %AAD of 5.7%.

Cao *et al.* (1993a) proposed three new equations, one for the viscosity of pure compounds, a second for the viscosities of liquid mixtures, and a third for the activity coefficients. They called their new model; the "viscosity-thermodynamics" model (UNIMOD). The equation that was suggested for the prediction of the viscosities of liquid mixture is given by

$$\ell n(\nu M) = \sum_{i=1}^{n} \phi_i \ell n(\nu_i M_i) + 2\sum_{i=1}^{n} \phi_i \ell n\left(\frac{x_i}{\varphi_i}\right) - \sum_{i=1}^{n} \frac{q_i n_i \phi_i}{r_i} \sum_{j=1}^{n} \theta_{ji} \tau_{ji} \tag{2.53}$$

where

$$\theta_{ji} = \frac{\theta_j \tau_{ji}}{\sum_{l=1}^{n} \theta_l \tau_{li}} \tag{2.54}$$

$$\theta_i = \frac{x_i q_i}{\sum_{j=1}^{n} x_j q_j} \tag{2.55}$$

$$\phi_i = \frac{x_i r_i}{\sum_{j=1}^{n} x_j r_j} \tag{2.56}$$

$$x_i = \frac{N_i}{\sum_{j=1}^{n} N_j} \tag{2.57}$$

The ϕ_i is defined as the average segment fraction of component i and r is the number of segments in a molecule i.

By combining the group-contribution approach with the UNIMOD model, Cao *et al.* (1993b) divided the viscosity equation into two parts: a combinatorial part and residual part. The equation is represented by

$$\ell n(\nu) = \sum_{i=1}^{n} \left[\zeta_i^C + \zeta_i^R \right] \tag{2.58}$$

where ζ_i^C and ζ_i^R are the combinatorial and the residual parts, respectively.

The combinatorial part is given by

$$\xi_i^C = \phi_i \ell n\left(\nu_i \frac{M_i}{M} \right) + 2\phi_i \ell n\left(\frac{x_i}{\phi_i} \right) \tag{2.59}$$

And the residual part is expressed by using group contribution as

$$\xi_i^R = \sum_{\text{all groups k}} \nu_k^{(i)} \left[\Xi_{ki} - \Xi_{ki}^{(i)} \right] \tag{2.60}$$

Cao *et al.* (1993b) expressed the GC-UNIMOD as follows

$$\ell n(\nu) = \sum_{i=1}^{n}\left[\phi_i \ell n\left(\nu_i \frac{M_i}{M}\right) + 2\phi_i \ell n\left(\frac{x_i}{\phi_i}\right) + \sum_{\text{all groups k}} \nu_k^{(i)}\left[\Xi_{ki} - \Xi_{ki}^{(i)}\right]\right] \tag{2.61}$$

where

$$\Xi_{mi} = -\frac{Q_m}{R_m} N_{mi}^{vis} \phi_i \sum_{\text{all groups k}} \theta_{km} \ell n(\Psi_{km}) \tag{2.62}$$

Ξ_{ki} is the group residual viscosity group k for component i in the mixture, $\Xi_{ki}^{(i)}$ is the group residual viscosity of group k for component i in the solution-of groups of pure liquid i in component i, $\nu_{ki}^{(i)}$ is the number of group k in molecule i, Q_k is the surface area parameter of group k, R_k is the volume parameter of group k, Ψ_{mn} is the group interaction parameters between groups m and n, and N_{mi}^{vis} is a group viscosity parameter for group k in component i and is given by

$$N_{mi}^{vis} = Q_k\left(\frac{q_i - r_i}{2} - \frac{1 - r_i}{z}\right) \tag{2.63}$$

where z is the co-ordination number and is equal to 10. In addition, q_i and r_i are the area parameters of molecule i and the number of segments of molecule i, respectively. They can be estimated by the following equations

$$q_i = \sum_{\text{all groups k}} \nu_k^{(i)} Q_k \tag{2.64}$$

$$r_i = \sum_{\text{all groups k}} \nu_k^{(i)} R_k \tag{2.65}$$

The local composition of groups, θ_{mn}, is calculated from

$$\theta_{mn} = \frac{\theta_m \Psi_{mn}}{\sum_{\text{all groups k}} \theta_k \Psi_{kn}} \tag{2.66}$$

where

$$\theta_m = \frac{x_m Q_m}{\sum_{\text{all groups k}} x_k Q_k} \tag{2.67}$$

and

$$\Psi_{mn} = \exp\left(-\frac{a_{mn}}{T}\right) \tag{2.68}$$

The parameter a_{mn}, in equation (2.68), is the group interaction energy parameter between groups m and n. This parameter is an adjustable parameter and is determined from experimental data. As indicated by Cao *et al.* (1993b), the interaction parameters a_{mn} are the same as those in the UNIFAC model.

2.2.3 The Generalized Corresponding States Principle (GCSP)

Teja and Rice (1981) utilized the corresponding states principle, that is employed in the prediction of thermodynamic properties of fluids, to develop what they reported as "the generalized corresponding states principle" (GCSP) for the prediction of the viscosity of liquid mixtures. They presented the following equation

$$\ell n(\eta\xi) = \ell n(\eta\xi)^{(r1)} + \frac{\omega - \omega^{(r1)}}{\omega^{(r2)} - \omega^{(r1)}}\left[\ell n(\eta\xi)^{(r2)} - \ell n(\eta\xi)^{(r1)}\right] \tag{2.69}$$

where η is the absolute viscosity, ω is the acentric factor of a non-spherical fluid, r1 and r2 refer to two non-spherical reference fluids, and ξ is expressed by the following formula

$$\xi = V_c^{2/3} T_c^{-1/2} M^{-1/2} \tag{2.70}$$

where V_c is the critical volume of the fluid and T_c is the critical temperature of the fluid.

To utilize equation (2.69) in case of mixtures and in order to replace T_c, V_c, ω, and M of a pure compound, the pseudocritical properties T_{cm}, V_{cm}, ω_m, and M_m were employed as follows

$$T_{cm} V_{cm} = \sum_{ij} \sum x_i x_j T_{cij} V_{cij} \tag{2.71}$$

$$V_{cm} = \sum_{ij} \sum x_i x_j V_{cij} \tag{2.72}$$

$$\omega_m = \sum_i x_i \omega_i \tag{2.73}$$

$$M_m = \sum_i x_i M_i \tag{2.74}$$

For the cross-parameters T_{cij} and V_{cij}, the following mixing rules were recommended by Teja and Rice (1981)

$$T_{cij} V_{cij} = \psi_{ij} \left(T_{ci} V_{ci} T_{cj} V_{cj} \right)^{1/2}; \qquad i \neq j \tag{2.75}$$

$$V_{cij} = \left(V_{ci}^{1/3} + V_{cj}^{1/3} \right) / 8 \tag{2.76}$$

The binary interaction parameter, in equation (2.75), is determined from experimental data. However, it can be assumed that the parameter is equal to unity in case of the absence of experimental data.

The GCSP method requires the knowledge of the critical properties of the compounds involved. Moreover, equation (2.69) requires selecting two reference fluids. In binary systems the two compounds can be directly selected whereas in multi-component systems one has to be careful in choosing the two reference compounds because different results are obtained for different selections. This evidently represents one of the major shortcomings of the GCSP. In order to overcome this problem, Wu and Asfour (1992) suggested the pseudo-binary mixture concept which reduces the number of components in a multi-component system to only two regardless of how many components are contained in the mixture. This cleverly circumvents the shortcomings of the GCSP. Wu and Asfour (1992) incorporated the pseudo-binary model into the GCSP and called the resulting model the modified generalized corresponding states principle (MGCSP).

2.3 Empirical Models for Predicting Liquid Mixtures Viscosity

2.3.1 The Allan and Teja correlation for viscosity

This correlation was proposed by Allan and Teja (1991) for predicting the absolute viscosity of defined and undefined hydrocarbon liquid mixtures. The Antoine-type equation they proposed is given by

$$\ell n(\eta) = A\left[-\frac{1}{B} + \frac{1}{T+C}\right] \tag{2.77}$$

The parameters A, B, and C were correlated with carbon number (n) in *n*-alkanes and they are expressed as follows

$$A = 145.73 + 99.01n + 0.83n^2 - 0.125n^3 \tag{2.78}$$

$$B = 30.48 + 34.04n - 1.23n^2 + 0.017n^3 \tag{2.79}$$

$$C = -3.07 - 1.99n \tag{2.80}$$

In order to obtain the effective carbon number for any hydrocarbon, a viscosity data point is required and a simple mole averaging mixing rule was used to determine the effective carbon number for the hydrocarbon mixture of interest. When compared with the Transport Properties Prediction method (TRAPP), developed by Ely and Hanley (1981), the Allan and Teja correlation performed better since it gave an estimated absolute average deviation (AAD) of 5.6% for ten binary systems whereas the TRAPP method gave an AAD of 9.5% for the same systems. Gregory (1992) recommended that the Allan and Teja correlation shouldn't be employed when the components have carbon numbers greater than 22.

CHAPTER 3

EXPERIMENTAL EQUIPMENT AND PROCEDURES

3.1 General

The main purpose of this chapter is to present the solutions preparation, the equipment employed, and the experimental procedures followed in order to measure the densities and viscosities of the systems investigated in this study. The following sections deal with a detailed discussion of the materials and experimental techniques employed in this study.

3.2 Materials

During the course of this study two types of chemicals were used: chemicals that were used in composing the systems of interest in this investigation, and chemicals that were used in calibrating the equipment. Hexane, heptane, octane, cyclohexane, toluene, and ethylbenzene were used to compose the systems and were purchased from Aldrich Chemical Company. Three viscosity standards; *viz.*, N1.0, N0.8, and N0.4 were employed to calibrate the viscometers. The calibration fluids were provided by Cannon Instruments Company. 1-hexanol, 1-heptanol, tridecane, pentane, p-xylene, double distilled water, and N0.4 were used in calibrating the density meter. The manufacturer's stated purities of all the chemicals were 99+%. In order to verify the stated purities, gas chromatographic analysis was carried-out by means of an HP5890 gas chromatograph equipped with an FID and an HP1 [cross linked methyl silicone gum] 30 m (long) × 0.53 mm (diameter) and 2.65 μm (film thickness) column. The column is covered by US Patent #4,293,415. The chemicals, their suppliers, and their stated and

verified purities are reported in Table 3.1. The double distilled water was prepared in the laboratory according to the procedure outlined by Asfour (1980).

3.3 Preparation of Solutions

The solutions were composed gravimetrically according to the procedure recommended by Asfour (1979). A mettler HK 160 balance with a precision of $\pm 2 \times 10^{-7}$ kg was used to weigh the samples. The samples were prepared in glass vials sealed with Tuf-Bond discs and aluminum seals supplied by Chromatographic Specialties Ltd. The vials were kept in a refrigerator until they were used in order to minimize evaporation losses.

The samples were composed in such a way that the more volatile component was injected into the vial first and weighed. To inject the samples into the vial, a 0.01 L hypodermic syringes fitted with size G23 or G24 needles were used. To take samples from the composed solutions, a 0.002 L hypodermic syringes fitted with size G24 needles were used.

3.4 Density Measurements

The densities of both the pure components and the mixtures were measured at 293.15 K and 298.15 K by using an Anton-Paar DMA 60/602 density meter. A pictorial view of the density meter and the temperature controlled chamber is shown in Figure 3.1. The density meter is kept inside a wooden chamber provided with a temperature controller. The density meter is connected to a Haake N4-B circulator and the

Table 3.1: Specifications of the Chemicals used in this Study

Supplier	Compound	Specification	GC analysis, mass%
Aldrich Chemical Company	Pentane	99+%	99.8
	Hexane	99+%	99.7
	Heptane	99+%	99.9
	p-xylene	99+%	99.7
	Ethylbenzene	99.80%	99.9
	Toluene	99.80%	99.9
	Cyclohexane	99+%	99.9
	Tridecane	99+%	99.8
	Octane	99+%	99.5
Fluka Chima	1-hexanol	>99% (GC)	99.1
	1-heptanol	>99% (GC)	99.7

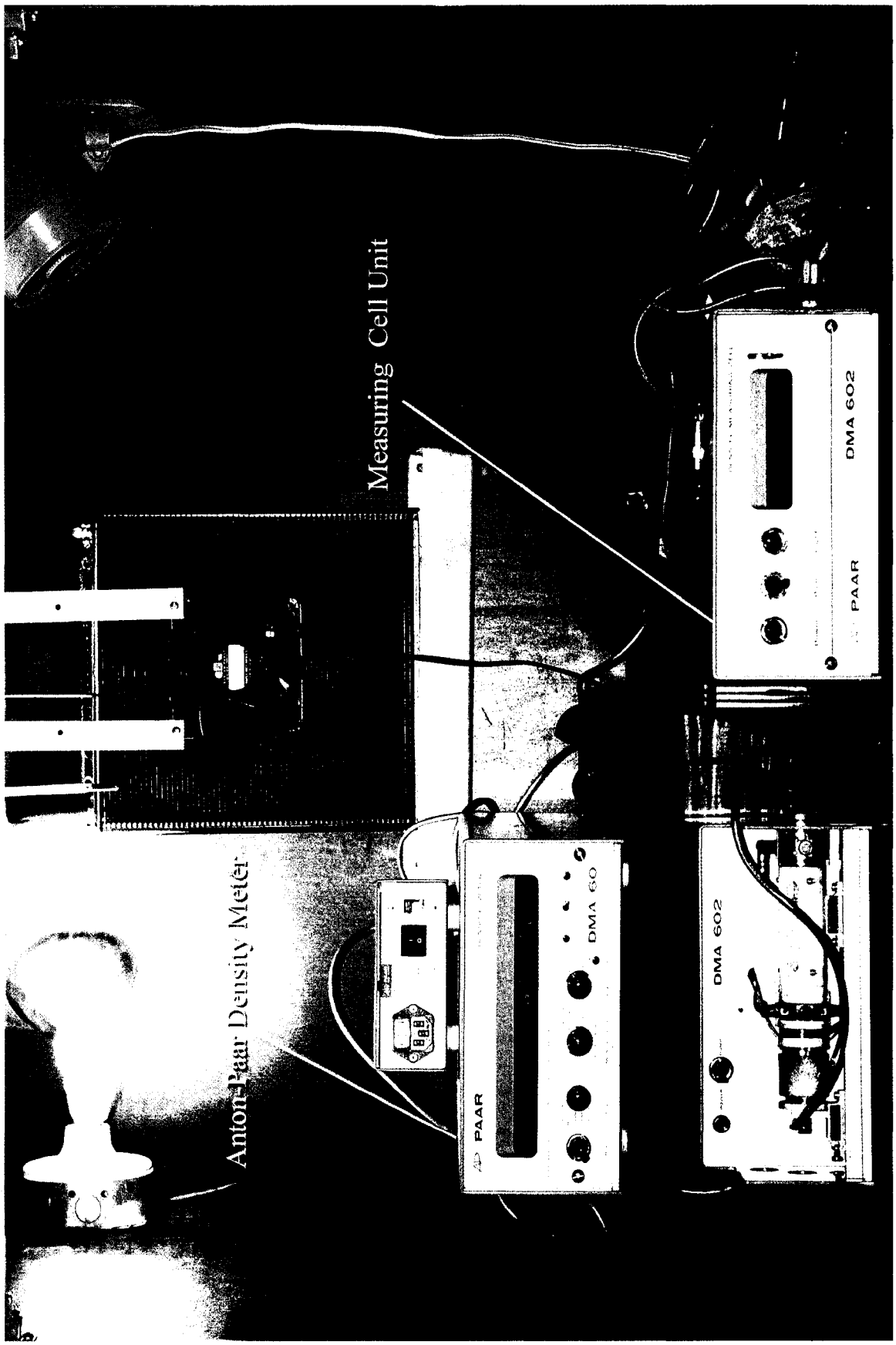

Figure 3.1: Pictorial View of the Anton-Paar Density Meter

temperature fluctuations within the measuring cell were kept within ± 0.01 K. The temperature fluctuations were monitored by an Omega electronic thermometer connected to a calibrated probe (ITS-90) with an accuracy of ± 0.005 K. The following equation was used to determine the density from the density meter readings:

$$\rho = \frac{A\tau^2}{1 - B\tau^2} - C \tag{3.1}$$

where ρ is the density and τ is the period of oscillation displayed by the density meter. The constants A, B, and C were determined at 293.15, 298.15, 308.15, and 313.15 K through the calibration of the density meter. Equation (3.1) was fitted, by using the least-squares method, to the density values of the calibration fluids. None of the components used in composing the investigated systems were employed in the calibration. The calibration results of both pure compounds and mixtures are reported in Chapter 4.

The density meter's measuring cell was flushed with ethanol and left to dry by blowing dry air into to the cell. The sample to be measured was injected carefully into the cell to avoid forming any air bubbles. The sample was left for about 15 minutes to achieve thermal equilibrium. Measurements were taken. A steady state is ensured when three consecutive readings are identical. Normally, ten readings are taken and an average value is taken. The ten frequency values recorded normally differed by only one digit in the sixth decimal place. The data for density meter measurements are reported in Appendix A.

Error analysis showed that the maximum fluctuation in density meter readings would result in an uncertainty of less than $\pm 1.5 \times 10^{-4}$ kg L^{-1} in the measured density value. Also, a temperature variation of $\pm$ 0.01 K would result in an approximate uncertainty of $\pm 3 \times 10^{-6}$ kg L^{-1} in the measured density.

3.5 Viscosity Measurement

The kinematic viscosities were measured by using a set of Cannon-Ubbelohde viscometers with a stated precision of $\pm$ 0.1%. The viscometers used were having the following numbers: 25B350, 25B365, 25B366, and 25B349 and covered the range of viscosities of (0.5-2.0) $\times 10^{-6}$ m^2 s^{-1}. In this study, the range of viscosities of systems investigated varied from 0.55 to 1.3 $\times 10^{-6}$ m^2 s^{-1}. Figure 3.2 shows a schematic diagram of the Cannon-Ubbelohde viscometer.

The kinematic viscosities were obtained by measuring the efflux time, t, and an average value of three repeated measurements was used.

The following equation was used to calculate the kinematic viscosity from the efflux times:

$$\nu = Et - \frac{F}{t^2} \tag{3.2}$$

where E and F are constants which were obtained by calibrating the viscometers by using calibration standards provided by Cannon Instruments Company. The ranges of these

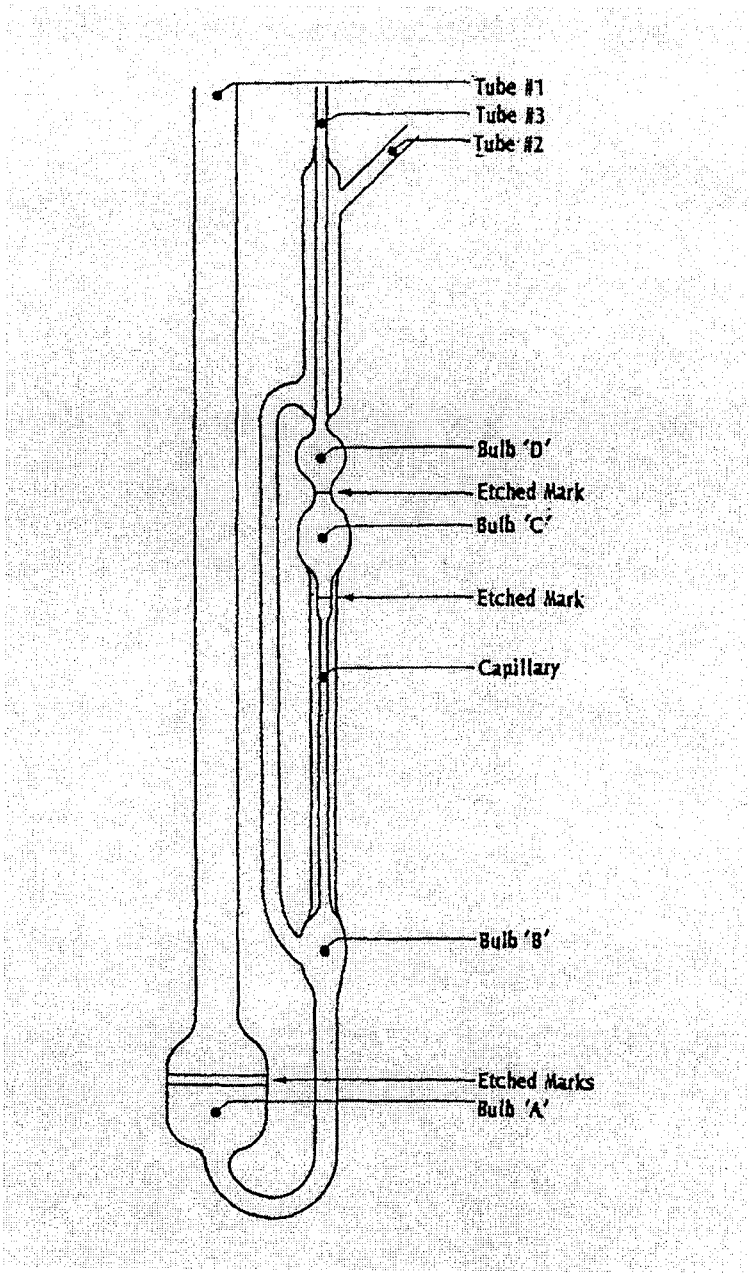

Figure 3.2: The Cannon-Ubbelohde Viscometer

standards cover the viscosity ranges under investigation. The calibration results are reported in Chapter 4. The Cannon-Ubbelohde viscometers were submerged into a model CT-1000 water-bath fitted with a temperature controller. Figure 3.3 shows a pictorial view of the CT-1000 constant temperature bath utilized in this study. The temperature fluctuations were controlled and kept to within ± 0.01 K. The temperature was monitored by an Omega DP95 digital RTD thermometer (ITS-90), which has a stated precision of ± 0.005K. The viscometers were left in the water-bath for about 30 minutes to allow the solutions inside the viscometers to reach thermal equilibrium. The efflux times were measured by using electronic stopwatches accurate to within ± 0.01 s.

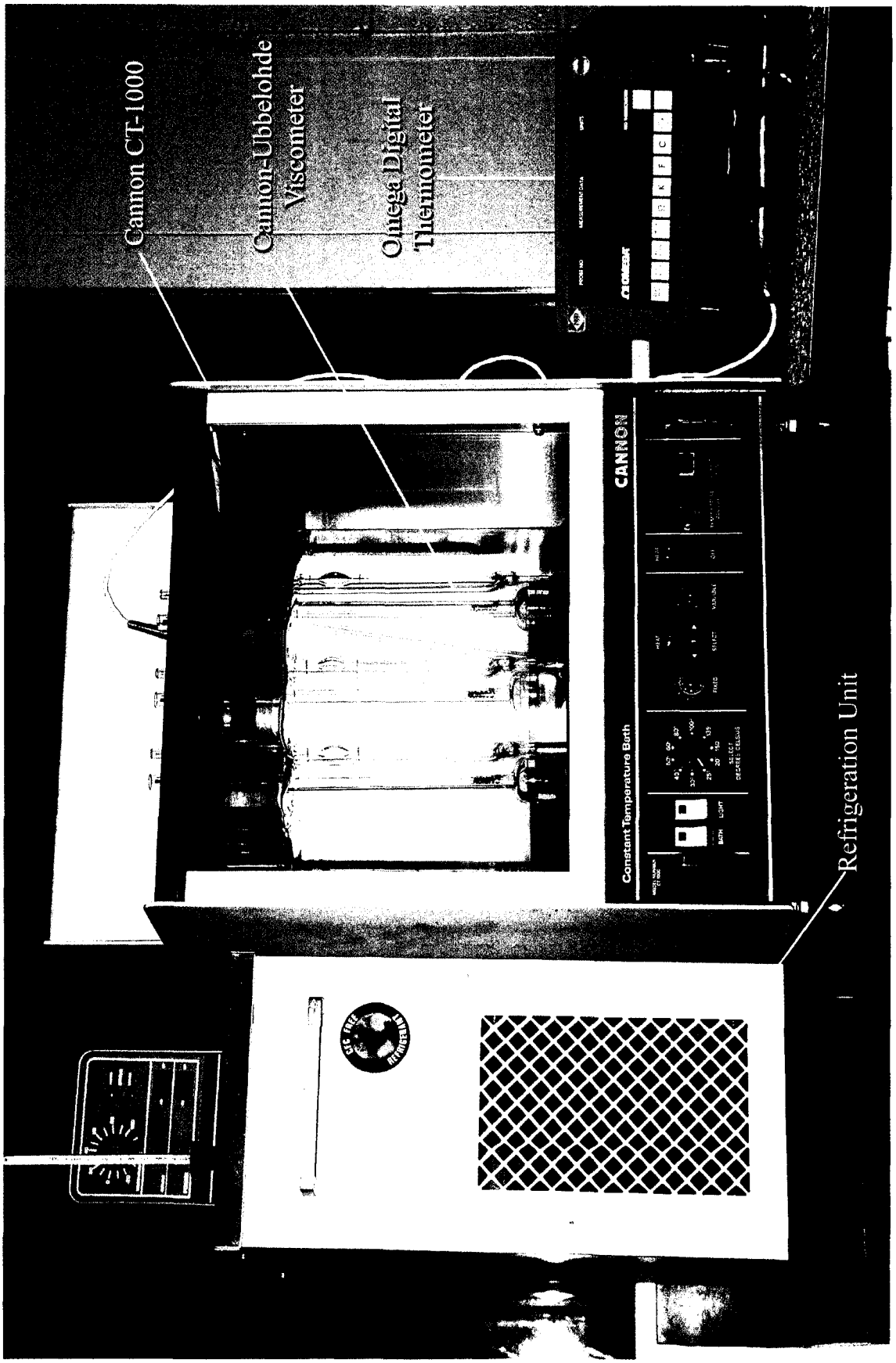

Figure 3.3: Pictorial View of the Viscosity Measuring and Temperature Control and Measuring Equipment

CHAPTER 4

EXPERIMENTAL RESULTS AND DISCUSSION

4.1 General

In this work, the viscosity and density data of ten binary subsystems of the quinary system: heptane + octane + cyclohexane + toluene + ethylbenzene were measured over the entire composition range at 293.15, 298.15, 308.15, and 313.15 K. In addition, the viscosities and densities of four binary systems and six ternary subsystems of the quinary system: hexane, octane, cyclohexane, toluene, and ethylbenzene were also measured over the entire composition range at 293.15 and 298.15 K. Table 4.1 presents the systems investigated in this study. Co-workers El-Hadad (2004) and Cai (2004) reported the viscosities and densities of the quinary and quaternary subsystems of the quinary systems referred to earlier herein. Therefore, the work reported herein complements their work.

It should be pointed out that the compounds involved in the investigated systems are of the non-associating type and that they significantly differ in shape and size. The data obtained in the present study were used to critically test the predictive capabilities of the literature viscosity models that were presented in Chapter 2.

Table 4.1: The Systems Investigated in the Present Work

1. The binary subsystems of the quinary system Heptane + Octane + Cyclohexane + Toluene + Ethylbenzene

Heptane (1) + Octane (2)
Heptane (1) + Cyclohexane (2)
Heptane (1) + Toluene (2)
Heptane (1) + Ethylbenzene (2)
Octane (1) + Cyclohexane (2)
Octane (1) + Toluene (2)
Octane (1)+ Ethylbenzene(2)
Cyclohexane (1) + Toluene (2)
Cyclohexane (1) + Ethylbenzene (2)
Toluene (1) + Ethylbenzene (2)

2. The Hexane-containing systems

(i) Binary systems

Hexane (1) + Octane (2)
Hexane (1) + Cyclohexane (2)
Hexane (1) + Toluene (2)
Hexane (1) + Ethylbenzene (2)

(ii) Ternary systems

Hexane (1) + Octane (2) + Ethylbenzene (3)
Hexane (1) + Octane (2) + Toluene (3)
Hexane (1) + Octane (2) + Cyclohexane (3)
Hexane (1) + Ethylbenzene (2) + Cyclohexane (3)
Hexane (1) + Ethylbenzene (2) + Toluene (3)
Hexane (1) + Cyclohexane (2) + Toluene (3)

4.2 Calibration Data of the Density Meter

The density meter was calibrated according to the procedure indicated earlier in Chapter 3. The materials used in calibrating the density meter were: Tridecane, p-xylene, double distilled water, 1-hexanol, 1-heptanol, and the viscosity standard N0.4. Equation (3.1) was employed to fit the data and obtain the meter constants at the investigated temperatures. The calibration results of the density meter along with the meter's constants are presented in Table 4.2.

4.3 Calibration Data of the Viscometers

The six Cannon-Ubbelhode viscometers employed in this study were calibrated by using three viscosity standards provided by Cannon Instruments Company. The viscosity standards cover the range of viscosities of all systems investigated in the study. The efflux time measured was an average of three consecutive measurements that were within $\pm$ 0.1%.

Equation (3.2) was employed to fit the data and obtain the two parameters for each viscometer. The results of the calibration are reported in Table 4.3.

Table 4.2: Calibration Data for the Density Meter

Substance	Temperature = 293.15 K		Source
	Density, kg/L	Density meter reading, Seconds	
Tridecane	0.7561	0.712920	TRC
p-xylene	0.861	0.732317	Timmermans, 1950
D D water	0.998234	0.757004	Perry, 1997
1-Hexanol	0.8198	0.724577	TRC
1-Heptanol	0.8223	0.725195	TRC
N0.4	0.6681	0.696142	Cannon Instr. Co.

Parameters of the density meter (equation 3.1)

A = 3.8828443

B = -0.0373463

C = 1.1802213

Standard Deviation of Fit (kg/L) = 1.40×10^{-4}

Substance	Temperature = 298.15 K		Source
	Density, kg/L	Density meter reading, Seconds	
Tridecane	0.75271	0.712008	TRC
p-xylene	0.85666	0.731279	Timmermans, 1950
D D water	0.99707	0.756544	Perry, 1997
1-Hexanol	0.8162	0.723676	TRC
1-Heptanol	0.8186	0.724302	TRC
N0.4	0.6635	0.695035	Cannon Instr. Co.

Parameters of the density meter (equation 3.1)

A = 3.8798055

B = -0.0360502

C = 1.1786852

Standard Deviation of Fit (kg/L) = 1.31×10^{-4}

Table 4.2 (Cont'd): Calibration Data for the Density Meter

Substance	Temperature = 308.15 K		Source
	Density, kg/L	Density meter reading, Seconds	
Tridecane	0.7459	0.710196	TRC
p-xylene	0.8478	0.729204	Timmermans, 1950
D D water	0.994061	0.755517	Perry, 1997
1-Hexanol	0.8080	0.721865	TRC
1-Heptanol	0.8117	0.722519	TRC
N0.4	0.6543	0.692807	Cannon Instr. Co.

Parameters of the density meter (equation 3.1)

A = 3.7442149

B = -0.0012367

C = 1.1416927

Standard Deviation of Fit (kg/L) = 5.77×10^{-5}

Substance	Temperature = 313.15 K		Source
	Density, kg/L	Density meter reading, Seconds	
Tridecane	0.7424	0.709292	TRC
p-xylene	0.8436	0.728168	Timmermans, 1950
D D water	0.9922497	0.754940	Perry, 1997
1-Hexanol	0.8054	0.720934	TRC
1-Heptanol	0.8077	0.721623	TRC
N0.4	0.6497	0.691683	Cannon Instr. Co.

Parameters of the density meter (equation 3.1)

A = 3.8407598

B = -0.0250097

C = 1.1660134

Standard Deviation of Fit (kg/L) = 1.70×10^{-4}

Table 4.3: Calibration Data for the Viscometers

T = 293.15 K

Viscometer	Viscosity Standard	Efflux time (s)	Standard Viscsoity $\times 10^6$ m^2/s	Parameters		Standard Deviation $\times 10^9$ m^2/s
				$E \times 10^9$ (m/s^2)	$F \times 10^6$ ($m^2.s$)	
25B365	N 0.4	264.67	0.483	0.0018341	200.3167	0.5019
	N 0.8	418.54	0.7652			
	N 1.0	689.60	1.265			
25B366	N 0.4	255.76	0.483	0.0018975	210.4467	1.066
	N 0.8	405.39	0.7652			
	N 1.0	666.20	1.265			
25B350	N 0.4	277.84	0.483	0.0017427	139.45564	0.712
	N 0.8	440.55	0.7652			
	N 1.0	725.51	1.265			
25B349	N 0.4	275.18	0.483	0.0017676	334.56266	1.197
	N 0.8	435.66	0.7652			
	N 1.0	715.19	1.265			

Table 4.3 (Cont'd) : Calibration Data for the Viscometers

T = 298.15 K

Viscometer	Viscosity Standard	Efflux time (s)	Standard Viscsoity $\times 10^6$ m^2/s	Parameters		Standard Deviation $\times 10^9$ m^2/s
				$E \times 10^9$ (m/s^2)	$F \times 10^6$ ($m^2.s$)	
25B365	N 0.4	253.40	0.4618	0.0018264	60.12428	0.7269
	N 0.8	395.32	0.7218			
	N 1.0	644.58	1.177			
25B366	N 0.4	245.65	0.4618	0.0018914	183.71619	0.2481
	N 0.8	382.62	0.7218			
	N 1.0	622.37	1.177			
25B350	N 0.4	265.98	0.4618	0.0017373	51.646136	0.5277
	N 0.8	416.44	0.7218			
	N 1.0	677.19	1.177			
25B349	N 0.4	263.51	0.4618	0.0017615	220.16951	0.9389
	N 0.8	411.89	0.7218			
	N 1.0	667.81	1.177			

Table 4.3 (Cont'd) : Calibration Data for the Viscometers

T = 308.15 K

Viscometer	Viscosity Standard	Efflux time (s)	Standard Viscsoity $\times 10^6$ m^2/s	Parameters		Standard Deviation $\times 10^9$ m^2/s
				$E \times 10^9$ (m/s^2)	$F \times 10^6$ ($m^2.s$)	
25B365	N 0.4	233.28	0.4618	0.0018236	9.9663459	0.09405
	N 0.8	355.80	0.7218			
	N 1.0	565.88	1.177			
25B366	N 0.4	225.41	0.4618	0.0018885	28.970868	0.2033
	N 0.8	343.80	0.7218			
	N 1.0	546.38	1.177			
25B350	N 0.4	244.98	0.4618	0.0017365	9.7523916	0.0597
	N 0.8	373.58	0.7218			
	N 1.0	594.27	1.177			
25B349	N 0.4	242.49	0.4618	0.0017604	115.62494	0.4254
	N 0.8	558.11	0.7218			
	N 1.0	369.48	1.177			

Table 4.3 (Cont'd) : Calibration Data for the Viscometers

T = 313.15 K

Viscometer	Viscosity Standard	Efflux time (s)	Standard Viscsoity $\times 10^6$ m^2/s	Parameters		Standard Deviation $\times 10^9$ m^2/s
				$E \times 10^9$ (m/s^2)	$F \times 10^6$ ($m^2.s$)	
25B365	N 0.4	224.12	0.4618	0.0018304	110.84632	0.5283
	N 0.8	338.14	0.7218			
	N 1.0	532.69	1.177			
25B366	N 0.4	216.51	0.4618	0.0018957	121.19435	0.7145
	N 0.8	326.83	0.7218			
	N 1.0	514.25	1.177			
25B350	N 0.4	235.42	0.4618	0.0017445	142.42539	0.4270
	N 0.8	354.74	0.7218			
	N 1.0	559.04	1.177			
25B349	N 0.4	232.73	0.4618	0.0017706	255.44113	1.276
	N 0.8	351.27	0.7218			
	N 1.0	550.41	1.177			

4.4 Accuracy and Precision of the Density and Viscosity Measurements

The densities and viscosities of the pure compounds constituting the mixtures investigated were measured at the temperatures 293.15, 298.15, 308.15, and 313.15 K. The experimental viscosity and density values of the pure components were compared with their corresponding values available in the literature. Tables 4.4 through 4.7 report this comparison. The experimental viscosity and density data obtained in the present study are clearly in excellent agreement with the values reported in the literature.

The slight differences in these values may be due to differences in the purities of the pure components used. In the present study, the purities of the pure components exceeded 99%. In addition, differences may occur because of temperature fluctuations. This is because densities and viscosities are functions of temperature. In the present study, temperature fluctuations were kept to within $\pm$ 0.01 K. Literature sources, in the majority of cases, do not clearly specify the purities of the compounds used and normally report temperature fluctuations higher than $\pm$ 0.01 K.

4.5 Viscometric and Volumetric Data of the Mixtures

Density and viscosity composition data were measured for the systems listed in Table 4.1. The density meter readings and efflux times were used in equations (3.1) and (3.2), respectively. Spreadsheets were utilized to perform the calculations. The values of densities, kinematic viscosities and absolute viscosities for all investigated systems over the entire composition range and at the temperatures employed in the present study are reported in Tables 4.8 and 4.9.

Table 4.4: Physical Properties of Pure Components at 293.15 K

Compound	Density, kg/L			Kinematic Viscosity $\times 10^6$ m^2/s			Absolute Viscosity $\times 10^3$ Pa.s		
	Experimental Value	Literature Value		Experimental Value	Literature Value		Experimental Value	Literature Value	
		Minimum	Maximum		Minimum	Maximum		Minimum	Maximum
Hexane	0.6594	0.65925 [1]	0.6595 [4]	0.4683	0.4695 [17]	0.4727 [1]	0.3088	0.3117 [1]	0.318 [4]
Heptane	0.6841	0.6836 [4]	0.68375 [1]	0.6008	0.59816 [4]	0.6096 [1]	0.4109	0.409 [4]	0.4169 [1]
Octane	0.7025	0.7022 [4]	0.70267 [1]	0.7738	0.7697 [17]	0.7758 [1]	0.5436	0.5450 [1]	0.5479 [8]
Toluene	0.8666	0.8666 [3]	0.8760 [2]	0.6766	0.6747 [1]	0.6786 [16]	0.5865	-	0.5848 [1]
Ethylbenzene	0.8671	0.860 [1]	0.8672 [4]	0.7786	-	0.7800 [1]	0.6750	-	0.6763 [1]
Cyclohexane	0.7785	0.7783 [4]	0.77856 [5]	1.2590	-	1.259 [17]	0.9801	-	-

[1] TRC Tables, 1988 [2] Timmermans 1950 [3] Asfour *et al.* 1990 [4] Nikolaos *et al.* 1995 [5] Cooper *et al.* 1991

[6] Geist *et al.* 1946 [7] Nhaesi 1998 [8] Lien *et al.* 2003 [9] ACS 1959 [10] Nayak *et al.* 2001

[11] Nath *et al.* 1997 [12] TRC Tables, 1998 [13] Aminabhavi 1996 [14] Gomez-Diaz *et al.* 2001 [15] Sanni *et al.* 1971

[16] Aminabhavi 1997 [17] Vavanellos 1991 [18] Bagga *et al.* 1970 [19] Puri and Raju 1970 [20] George *et al.* 2003

[21] Ritzoulis *et al.* 1986 [22] Hafez *et al.* 1976 [23] Garcia *et al.* 1986 [24] Ramesh *et al.* 1989 [25] Rao and Suri 1980

Table 4.5: Physical Properties of Pure Components at 298.15 K

Compound	Density, kg/L			Kinematic Viscosity × 10^6 m^2/s			Absolute Viscosity × 10^3 Pa.s		
	Experimental Value	Literature Value		Experimental Value	Literature Value		Experimental Value	Literature Value	
		Minimum	Maximum		Minimum	Maximum		Minimum	Maximum
Hexane	0.6549	0.65471 [1]	0.65502 [4]	0.4488	0.447 [18]	0.4545 [1]	0.2939	0.2937 [4]	0.3150 [14]
Heptane	0.6798	0.6793 [6]	0.67963 [4]	0.5716	0.56722 [8]	0.5821 [1]	0.3885	0.3855 [4]	0.4040 [14]
Octane	0.6985	0.67849 [6]	0.69862 [1]	0.7302	0.72975 [17]	0.7352 [1]	0.5100	0.5136 [1]	0.5030 [14]
Toluene	0.8623	0.8610 [7]	0.86232 [8]	0.6405	0.6378 [1]	0.6421 [12]	0.5523	0.5500 [1]	0.5560 [15]
Ethylbenzene	0.8627	0.8621 [9]	0.8630 [10]	0.7335	0.7299 [18]	0.7367 [1]	0.6328	-	0.6345 [1]
Cyclohexane	0.7740	0.7711 [11]	0.77399 [8]	1.1599	1.1335 [13]	1.1616 [11]	0.8976	0.8770 [13]	0.8958 [11]

Table 4.6: Physical Properties of Pure Components at 308.15 K

Compound	Density, kg/L			Kinematic Viscosity $\times 10^6$ m^2/s			Absolute Viscosity $\times 10^3$ Pa.s		
	Experimental Value	Literature Value		Experimental Value	Literature Value		Experimental Value	Literature Value	
		Minimum	Maximum		Minimum	Maximum		Minimum	Maximum
Heptane	0.6714	0.6705 [10]		0.5212	-	0.5336 [1]	0.3498	0.6705 [10]	0.3581 [1]
Octane	0.6904	0.6900 [10]	0.6984 [16]	0.6583	0.6580 [17]	0.6649 [1]	0.4545	0.4450 [10]	0.4591 [1]
Toluene	0.8527	0.8527 [21]	0.8531 [4]	0.5756	0.5741 [1]	0.5783 [17]	0.4908	0.4898 [1]	0.4928 [22]
Ethylbenzene	0.8536	0.8497 [18]	0.8548 [19]	0.6590	0.6565 [17]	0.6614 [1]	0.5626	0.5340 [20]	0.5645 [1]
Cyclohexane	0.7643	0.7597 [12]	0.7643 [13]	0.9951	0.9930 [1]	-	0.7605	0.7544 [12]	0.7575 [14]

Table 4.7: Physical Properties of Pure Components at 313.15 K

Compound	Density, kg/L			Kinematic Viscosity × 10^6 m^2/s			Absolute Viscosity × 10^3 Pa.s		
	Experimental Value	Literature Value		Experimental Value	Literature Value		Experimental Value	Literature Value	
		Minimum	Maximum		Minimum	Maximum		Minimum	Maximum
Heptane	0.6671	0.6665 [1]	-	0.4997	0.4990 [6]	0.5112 [1]	0.3333	0.3330 [6]	0.3416 [1]
Octane	0.6864	0.6863 [1]	0.6904 [23]	0.6282	0.6261 [17]	0.6343 [1]	0.4312	0.4295 [4]	0.4355 [1]
Toluene	0.8483	0.8472 [25]	0.8485 [1]	0.5493	0.5465 [1]	0.5508 [17]	0.4659	0.4636 [1]	0.4851 [25]
Ethylbenzene	0.8494	0.8495 [1]	0.8598 [24]	0.6281	0.6242 [17]	0.6286 [1]	0.5336	-	0.5338 [1]
Cyclohexane	0.7597	0.7562 [12]	0.7596 [13]	0.9317	0.9260 [6]	0.9230 [1]	0.7078	0.6980 [12]	0.6995 [14]

Table 4.8: Densities and Viscosities of the Binary System: Cyclohexane (1) + Ethylbenzene (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7787	1.2590	0.9804
0.0000	1.0000	0.8671	0.7786	0.6751
0.1165	0.8835	0.8568	0.7809	0.6691
0.1927	0.8073	0.8498	0.7847	0.6669
0.2965	0.7035	0.8404	0.7977	0.6704
0.4034	0.5966	0.8307	0.8138	0.6761
0.5021	0.4979	0.8218	0.8426	0.6925
0.5952	0.4048	0.8135	0.8780	0.7143
0.6964	0.3036	0.8045	0.9246	0.7439
0.7876	0.2124	0.7965	0.9907	0.7891
0.9118	0.0882	0.7859	1.1218	0.8816

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Cyclohexane (1) + Ethylbenzene (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7740	1.1599	0.8978
0.0000	1.0000	0.8627	0.7335	0.6328
0.1165	0.8835	0.8523	0.7315	0.6235
0.1927	0.8073	0.8454	0.7387	0.6245
0.2965	0.7035	0.8360	0.7502	0.6272
0.4034	0.5966	0.8263	0.7651	0.6322
0.5021	0.4979	0.8173	0.7905	0.6461
0.5952	0.4048	0.8089	0.8223	0.6652
0.6964	0.3036	0.7999	0.8654	0.6922
0.7876	0.2124	0.7918	0.9233	0.7311
0.9118	0.0882	0.7812	1.0369	0.8101

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Cyclohexane (1) + Ethylbenzene (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7643	0.9951	0.7606
0.0000	1.0000	0.8536	0.6590	0.5625
0.1165	0.8835	0.8433	0.6588	0.5555
0.1927	0.8073	0.8363	0.6658	0.5568
0.2965	0.7035	0.8268	0.6737	0.5570
0.4034	0.5966	0.8170	0.6868	0.5611
0.5021	0.4979	0.8081	0.7076	0.5718
0.5952	0.4048	0.7996	0.7324	0.5856
0.6964	0.3036	0.7905	0.7666	0.6060
0.7876	0.2124	0.7824	0.8123	0.6355
0.9118	0.0882	0.7716	0.9002	0.6946

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Cyclohexane (1) + Ethylbenzene (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7597	0.9317	0.7078
0.0000	1.0000	0.8494	0.6281	0.5335
0.1165	0.8835	0.8391	0.6286	0.5275
0.1927	0.8073	0.8320	0.6337	0.5272
0.2965	0.7035	0.8226	0.6421	0.5282
0.4034	0.5966	0.8128	0.6545	0.5320
0.5021	0.4979	0.8037	0.6729	0.5408
0.5952	0.4048	0.7953	0.6952	0.5529
0.6964	0.3036	0.7861	0.7272	0.5716
0.7876	0.2124	0.7780	0.7673	0.5969
0.9118	0.0882	0.7671	0.8460	0.6490

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Cyclohexane (1) + Toluene (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7787	1.2590	0.9804
0.0000	1.0000	0.8666	0.6766	0.5864
0.0960	0.9040	0.8570	0.6864	0.5883
0.1961	0.8039	0.8469	0.7011	0.5938
0.2952	0.7048	0.8372	0.7206	0.6033
0.3960	0.6040	0.8276	0.7441	0.6158
0.4872	0.5128	0.8193	0.7779	0.6373
0.5916	0.4084	0.8100	0.8275	0.6702
0.6896	0.3104	0.8018	0.8843	0.7090
0.7886	0.2114	0.7939	0.9661	0.7670
0.8968	0.1032	0.7858	1.0915	0.8577

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Cyclohexane (1) + Toluene (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7740	1.1599	0.8978
0.0000	1.0000	0.8623	0.6406	0.5524
0.0960	0.9040	0.8524	0.6475	0.5519
0.1961	0.8039	0.8423	0.6608	0.5566
0.2952	0.7048	0.8325	0.6792	0.5654
0.3960	0.6040	0.8229	0.6996	0.5757
0.4872	0.5128	0.8146	0.7293	0.5941
0.5916	0.4084	0.8054	0.7747	0.6239
0.6896	0.3104	0.7971	0.8277	0.6598
0.7886	0.2114	0.7893	0.9002	0.7105
0.8968	0.1032	0.7811	1.0102	0.7890

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Cyclohexane (1) + Toluene (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7643	0.9951	0.7606
0.0000	1.0000	0.8527	0.5756	0.4908
0.0960	0.9040	0.8428	0.5834	0.4917
0.1961	0.8039	0.8327	0.5951	0.4956
0.2952	0.7048	0.8230	0.6103	0.5023
0.3960	0.6040	0.8134	0.6284	0.5111
0.4872	0.5128	0.8050	0.6537	0.5263
0.5916	0.4084	0.7958	0.6927	0.5512
0.6896	0.3104	0.7875	0.7331	0.5773
0.7886	0.2114	0.7796	0.7917	0.6172
0.8968	0.1032	0.7715	0.8780	0.6774

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Cyclohexane (1) + Toluene (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7597	0.9317	0.7078
0.0000	1.0000	0.8483	0.5493	0.4660
0.0960	0.9040	0.8383	0.5569	0.4669
0.1961	0.8039	0.8282	0.5742	0.4755
0.2952	0.7048	0.8185	0.5893	0.4824
0.3960	0.6040	0.8089	0.5987	0.4843
0.4872	0.5128	0.8005	0.6220	0.4979
0.5916	0.4084	0.7913	0.6549	0.5182
0.6896	0.3104	0.7830	0.6944	0.5437
0.7886	0.2114	0.7751	0.7473	0.5793
0.8968	0.1032	0.7670	0.8251	0.6328

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Cyclohexane (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6841	0.6008	0.4110
0.0000	1.0000	0.7787	1.2590	0.9804
0.1008	0.8992	0.7651	1.0818	0.8277
0.2140	0.7860	0.7513	0.9496	0.7135
0.3027	0.6973	0.7416	0.8724	0.6470
0.3915	0.6085	0.7326	0.8175	0.5989
0.4864	0.5136	0.7236	0.7635	0.5525
0.5875	0.4125	0.7148	0.7253	0.5184
0.6977	0.3023	0.7057	0.6921	0.4884
0.7813	0.2187	0.6993	0.6528	0.4565
0.9063	0.0937	0.6904	0.6215	0.4291

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Cyclohexane (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6798	0.5716	0.3886
0.0000	1.0000	0.7740	1.1599	0.8978
0.1008	0.8992	0.7606	1.0443	0.7943
0.2140	0.7860	0.7469	0.9044	0.6755
0.3027	0.6973	0.7372	0.8180	0.6030
0.3915	0.6085	0.7282	0.7666	0.5582
0.4864	0.5136	0.7193	0.7177	0.5162
0.5875	0.4125	0.7104	0.6803	0.4833
0.6977	0.3023	0.7015	0.6451	0.4526
0.7813	0.2187	0.6951	0.6198	0.4308
0.9063	0.0937	0.6861	0.5974	0.4098

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Cyclohexane (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6714	0.5212	0.3500
0.0000	1.0000	0.7643	0.9951	0.7606
0.1008	0.8992	0.7512	0.8735	0.6561
0.2140	0.7860	0.7377	0.7800	0.5754
0.3027	0.6973	0.7281	0.7263	0.5288
0.3915	0.6085	0.7193	0.6826	0.4910
0.4864	0.5136	0.7105	0.6438	0.4574
0.5875	0.4125	0.7017	0.6121	0.4295
0.6977	0.3023	0.6928	0.5828	0.4038
0.7813	0.2187	0.6865	0.5622	0.3859
0.9063	0.0937	0.6776	0.5380	0.3646

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Cyclohexane (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6671	0.4997	0.3334
0.0000	1.0000	0.7597	0.9317	0.7078
0.1008	0.8992	0.7467	0.8219	0.6137
0.2140	0.7860	0.7332	0.7374	0.5406
0.3027	0.6973	0.7237	0.6886	0.4984
0.3915	0.6085	0.7149	0.6498	0.4646
0.4864	0.5136	0.7061	0.6134	0.4331
0.5875	0.4125	0.6974	0.5832	0.4067
0.6977	0.3023	0.6885	0.5569	0.3834
0.7813	0.2187	0.6822	0.5379	0.3670
0.9063	0.0937	0.6733	0.5157	0.3472

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Ethylbenzene (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6841	0.6008	0.4110
0.0000	1.0000	0.8671	0.7786	0.6751
0.1151	0.8849	0.8423	0.7272	0.6125
0.2217	0.7783	0.8234	0.7018	0.5779
0.2997	0.7003	0.8045	0.6767	0.5444
0.3878	0.6122	0.7879	0.6534	0.5148
0.4805	0.5195	0.7708	0.6386	0.4922
0.5896	0.4104	0.7511	0.6261	0.4702
0.6895	0.3105	0.7339	0.6138	0.4504
0.7993	0.2007	0.7157	0.6067	0.4342
0.8731	0.1269	0.7038	0.6046	0.4256

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Ethylbenzene (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6798	0.5716	0.3886
0.0000	1.0000	0.8627	0.7335	0.6328
0.1151	0.8849	0.8379	0.6888	0.5772
0.2217	0.7783	0.8191	0.6642	0.5440
0.2997	0.7003	0.8001	0.6419	0.5136
0.3878	0.6122	0.7836	0.6219	0.4873
0.4805	0.5195	0.7663	0.6079	0.4659
0.5896	0.4104	0.7468	0.5955	0.4447
0.6895	0.3105	0.7296	0.5842	0.4263
0.7993	0.2007	0.7114	0.5775	0.4108
0.8731	0.1269	0.6996	0.5758	0.4028

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Ethylbenzene (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6714	0.5212	0.3500
0.0000	1.0000	0.8536	0.6590	0.5625
0.1151	0.8849	0.8289	0.6225	0.5160
0.2217	0.7783	0.8101	0.6021	0.4878
0.2997	0.7003	0.7912	0.5819	0.4604
0.3878	0.6122	0.7747	0.5653	0.4380
0.4805	0.5195	0.7575	0.5540	0.4197
0.5896	0.4104	0.7380	0.5422	0.4001
0.6895	0.3105	0.7209	0.5342	0.3851
0.7993	0.2007	0.7028	0.5277	0.3709
0.8731	0.1269	0.6910	0.5267	0.3640

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Ethylbenzene (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6671	0.4997	0.3334
0.0000	1.0000	0.8494	0.6281	0.5335
0.1151	0.8849	0.8248	0.5948	0.4906
0.2217	0.7783	0.8060	0.5753	0.4637
0.2997	0.7003	0.7871	0.5568	0.4383
0.3878	0.6122	0.7706	0.5417	0.4174
0.4805	0.5195	0.7533	0.5305	0.3996
0.5896	0.4104	0.7339	0.5198	0.3815
0.6895	0.3105	0.7167	0.5111	0.3663
0.7993	0.2007	0.6986	0.5058	0.3533
0.8731	0.1269	0.6868	0.5033	0.3457

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Octane (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6841	0.6008	0.4110
0.0000	1.0000	0.7025	0.7738	0.5436
0.1141	0.8859	0.7006	0.7526	0.5273
0.2198	0.7802	0.6988	0.7323	0.5117
0.2916	0.7084	0.6976	0.7198	0.5022
0.3867	0.6133	0.6959	0.7009	0.4877
0.4751	0.5249	0.6943	0.6922	0.4806
0.5820	0.4180	0.6923	0.6734	0.4662
0.6794	0.3206	0.6905	0.6475	0.4471
0.7798	0.2202	0.6885	0.6343	0.4367
0.9042	0.0958	0.6866	0.6179	0.4242

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Octane (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6798	0.5716	0.3886
0.0000	1.0000	0.6985	0.7303	0.5101
0.1141	0.8859	0.6966	0.7112	0.4954
0.2198	0.7802	0.6948	0.6926	0.4812
0.2916	0.7084	0.6935	0.6816	0.4727
0.3867	0.6133	0.6918	0.6649	0.4600
0.4751	0.5249	0.6901	0.6565	0.4531
0.5820	0.4180	0.6882	0.6380	0.4391
0.6794	0.3206	0.6863	0.6167	0.4233
0.7798	0.2202	0.6843	0.6037	0.4131
0.9042	0.0958	0.6824	0.5872	0.4007

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Octane (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6714	0.5212	0.3500
0.0000	1.0000	0.6904	0.6583	0.4545
0.1141	0.8859	0.6885	0.6422	0.4421
0.2198	0.7802	0.6866	0.6260	0.4298
0.2916	0.7084	0.6853	0.6166	0.4226
0.3867	0.6133	0.6836	0.6017	0.4113
0.4751	0.5249	0.6819	0.5938	0.4049
0.5820	0.4180	0.6799	0.5787	0.3935
0.6794	0.3206	0.6780	0.5607	0.3802
0.7798	0.2202	0.6760	0.5500	0.3718
0.9042	0.0958	0.6740	0.5347	0.3604

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Octane (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6671	0.4997	0.3334
0.0000	1.0000	0.6864	0.6282	0.4312
0.1141	0.8859	0.6845	0.6140	0.4203
0.2198	0.7802	0.6826	0.5983	0.4084
0.2916	0.7084	0.6813	0.5901	0.4020
0.3867	0.6133	0.6795	0.5756	0.3911
0.4751	0.5249	0.6778	0.5675	0.3846
0.5820	0.4180	0.6758	0.5537	0.3742
0.6794	0.3206	0.6738	0.5371	0.3619
0.7798	0.2202	0.6718	0.5268	0.3539
0.9042	0.0958	0.6697	0.5122	0.3430

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Toluene (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6841	0.6008	0.4110
0.0000	1.0000	0.8666	0.6766	0.5864
0.1031	0.8969	0.8418	0.6457	0.5436
0.2160	0.7840	0.8163	0.6214	0.5072
0.2980	0.7020	0.7989	0.6109	0.4880
0.3860	0.6140	0.7814	0.5996	0.4685
0.4821	0.5179	0.7634	0.5933	0.4529
0.5864	0.4136	0.7452	0.5913	0.4406
0.6952	0.3048	0.7275	0.5859	0.4262
0.7831	0.2169	0.7141	0.5889	0.4205
0.9064	0.0936	0.6971	0.5946	0.4145

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Toluene (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6798	0.5716	0.3886
0.0000	1.0000	0.8623	0.6406	0.5524
0.1031	0.8969	0.8372	0.6119	0.5122
0.2160	0.7840	0.8117	0.5897	0.4786
0.2980	0.7020	0.7944	0.5798	0.4606
0.3860	0.6140	0.7769	0.5702	0.4430
0.4821	0.5179	0.7589	0.5636	0.4277
0.5864	0.4136	0.7408	0.5615	0.4160
0.6952	0.3048	0.7232	0.5583	0.4038
0.7831	0.2169	0.7098	0.5605	0.3979
0.9064	0.0936	0.6928	0.5666	0.3925

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Toluene (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6714	0.5212	0.3500
0.0000	1.0000	0.8527	0.5756	0.4908
0.1031	0.8969	0.8278	0.5537	0.4583
0.2160	0.7840	0.8024	0.5367	0.4306
0.2980	0.7020	0.7851	0.5272	0.4139
0.3860	0.6140	0.7678	0.5203	0.3995
0.4821	0.5179	0.7499	0.5146	0.3859
0.5864	0.4136	0.7319	0.5127	0.3752
0.6952	0.3048	0.7143	0.5095	0.3640
0.7831	0.2169	0.7011	0.5128	0.3595
0.9064	0.0936	0.6843	0.5170	0.3538

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Heptane (1) + Toluene (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6671	0.4997	0.3334
0.0000	1.0000	0.8483	0.5493	0.4660
0.1031	0.8969	0.8233	0.5294	0.4359
0.2160	0.7840	0.7980	0.5126	0.4091
0.2980	0.7020	0.7808	0.5045	0.3939
0.3860	0.6140	0.7635	0.4974	0.3797
0.4821	0.5179	0.7456	0.4930	0.3676
0.5864	0.4136	0.7276	0.4915	0.3576
0.6952	0.3048	0.7101	0.4887	0.3470
0.7831	0.2169	0.6968	0.4913	0.3423
0.9064	0.0936	0.6800	0.4956	0.3370

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Cyclohexane (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7025	0.7738	0.5436
0.0000	1.0000	0.7785	1.2590	0.9801
0.0847	0.9153	0.7681	1.1150	0.8565
0.2029	0.7971	0.7554	1.0080	0.7615
0.2843	0.7157	0.7476	0.9456	0.7069
0.3956	0.6044	0.7385	0.8995	0.6643
0.4963	0.5037	0.7311	0.8691	0.6354
0.6017	0.3983	0.7240	0.8401	0.6082
0.6782	0.3218	0.7193	0.8231	0.5921
0.8081	0.1919	0.7120	0.7990	0.5689
0.8992	0.1008	0.7074	0.7854	0.5556

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Cyclohexane (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6985	0.7303	0.5101
0.0000	1.0000	0.7740	1.1599	0.8978
0.0847	0.9153	0.7635	1.0407	0.7946
0.2029	0.7971	0.7510	0.9455	0.7101
0.2843	0.7157	0.7435	0.8901	0.6618
0.3956	0.6044	0.7342	0.8488	0.6232
0.4963	0.5037	0.7268	0.8198	0.5958
0.6017	0.3983	0.7198	0.7927	0.5706
0.6782	0.3218	0.7151	0.7761	0.5550
0.8081	0.1919	0.7079	0.7548	0.5344
0.8992	0.1008	0.7033	0.7423	0.5220

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Cyclohexane (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6904	0.6583	0.4545
0.0000	1.0000	0.7643	0.9951	0.7606
0.0847	0.9153	0.7542	0.9069	0.6840
0.2029	0.7971	0.7419	0.8328	0.6178
0.2843	0.7157	0.7345	0.7887	0.5793
0.3956	0.6044	0.7255	0.7559	0.5484
0.4963	0.5037	0.7182	0.7316	0.5254
0.6017	0.3983	0.7113	0.7089	0.5043
0.6782	0.3218	0.7068	0.6961	0.4920
0.8081	0.1919	0.6997	0.6791	0.4751
0.8992	0.1008	0.6951	0.6677	0.4641

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Cyclohexane (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6864	0.6282	0.4312
0.0000	1.0000	0.7597	0.9317	0.7078
0.0847	0.9153	0.7497	0.8528	0.6394
0.2029	0.7971	0.7376	0.7868	0.5803
0.2843	0.7157	0.7302	0.7467	0.5453
0.3956	0.6044	0.7213	0.7172	0.5173
0.4963	0.5037	0.7141	0.6955	0.4967
0.6017	0.3983	0.7072	0.6747	0.4771
0.6782	0.3218	0.7027	0.6635	0.4663
0.8081	0.1919	0.6956	0.6470	0.4501
0.8992	0.1008	0.6911	0.6371	0.4403

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Ethylbenzene (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7025	0.7738	0.5436
0.0000	1.0000	0.8666	0.7786	0.6748
0.1005	0.8995	0.8452	0.7530	0.6364
0.1909	0.8091	0.8271	0.7482	0.6188
0.3003	0.6997	0.8064	0.7319	0.5902
0.3947	0.6053	0.7897	0.7249	0.5725
0.4910	0.5090	0.7737	0.7265	0.5621
0.5964	0.4036	0.7572	0.7301	0.5528
0.7047	0.2953	0.7413	0.7330	0.5434
0.7846	0.2154	0.7302	0.7399	0.5403
0.9086	0.0914	0.7139	0.7600	0.5425

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Ethylbenzene (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6985	0.7303	0.5101
0.0000	1.0000	0.8627	0.7335	0.6328
0.1005	0.8995	0.8410	0.7095	0.5967
0.1909	0.8091	0.8228	0.6976	0.5740
0.3003	0.6997	0.8021	0.6908	0.5541
0.3947	0.6053	0.7855	0.6846	0.5378
0.4910	0.5090	0.7695	0.6853	0.5273
0.5964	0.4036	0.7530	0.6884	0.5184
0.7047	0.2953	0.7371	0.6943	0.5118
0.7846	0.2154	0.7261	0.7018	0.5096
0.9086	0.0914	0.7099	0.7177	0.5095

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Ethylbenzene (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6904	0.6583	0.4545
0.0000	1.0000	0.8536	0.6590	0.5625
0.1005	0.8995	0.8321	0.6412	0.5336
0.1909	0.8091	0.8139	0.6364	0.5179
0.3003	0.6997	0.7934	0.6258	0.4965
0.3947	0.6053	0.7768	0.6209	0.4824
0.4910	0.5090	0.7609	0.6222	0.4734
0.5964	0.4036	0.7446	0.6249	0.4653
0.7047	0.2953	0.7288	0.6286	0.4581
0.7846	0.2154	0.7178	0.6348	0.4557
0.9086	0.0914	0.7017	0.6474	0.4543

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Ethylbenzene (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6864	0.6282	0.4312
0.0000	1.0000	0.8494	0.6281	0.5335
0.1005	0.8995	0.8279	0.6125	0.5071
0.1909	0.8091	0.8098	0.6092	0.4934
0.3003	0.6997	0.7893	0.5977	0.4718
0.3947	0.6053	0.7728	0.5941	0.4592
0.4910	0.5090	0.7569	0.5949	0.4502
0.5964	0.4036	0.7406	0.5990	0.4436
0.7047	0.2953	0.7248	0.6014	0.4359
0.7846	0.2154	0.7138	0.6069	0.4332
0.9086	0.0914	0.6977	0.6183	0.4314

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Toluene (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.7025	0.7738	0.5436
0.0000	1.0000	0.8666	0.6766	0.5864
0.0906	0.9094	0.8445	0.6642	0.5609
0.1955	0.8045	0.8213	0.6612	0.5431
0.3008	0.6992	0.8003	0.6630	0.5306
0.3953	0.6047	0.7833	0.6672	0.5226
0.4955	0.5045	0.7668	0.6787	0.5204
0.5924	0.4076	0.7523	0.6919	0.5205
0.6721	0.3279	0.7412	0.7011	0.5197
0.8025	0.1975	0.7246	0.7260	0.5260
0.8985	0.1015	0.7135	0.7480	0.5337

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Toluene (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6985	0.7303	0.5101
0.0000	1.0000	0.8623	0.6406	0.5524
0.0906	0.9094	0.8399	0.6291	0.5284
0.1955	0.8045	0.8168	0.6257	0.5111
0.3008	0.6992	0.7959	0.6285	0.5002
0.3953	0.6047	0.7789	0.6311	0.4915
0.4955	0.5045	0.7625	0.6401	0.4880
0.5924	0.4076	0.7480	0.6527	0.4882
0.6721	0.3279	0.7370	0.6651	0.4902
0.8025	0.1975	0.7205	0.6878	0.4955
0.8985	0.1015	0.7094	0.7071	0.5016

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Toluene (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6904	0.6583	0.4545
0.0000	1.0000	0.8527	0.5756	0.4908
0.0906	0.9094	0.8306	0.5688	0.4724
0.1955	0.8045	0.8076	0.5669	0.4579
0.3008	0.6992	0.7868	0.5696	0.4482
0.3953	0.6047	0.7700	0.5737	0.4418
0.4955	0.5045	0.7537	0.5829	0.4393
0.5924	0.4076	0.7394	0.5948	0.4398
0.6721	0.3279	0.7285	0.6054	0.4410
0.8025	0.1975	0.7122	0.6220	0.4430
0.8985	0.1015	0.7012	0.6405	0.4491

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Octane (1) + Toluene (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6864	0.6282	0.4312
0.0000	1.0000	0.8483	0.5493	0.4660
0.0906	0.9094	0.8262	0.5432	0.4488
0.1955	0.8045	0.8033	0.5420	0.4354
0.3008	0.6992	0.7826	0.5447	0.4263
0.3953	0.6047	0.7658	0.5490	0.4205
0.4955	0.5045	0.7496	0.5575	0.4179
0.5924	0.4076	0.7353	0.5690	0.4184
0.6721	0.3279	0.7244	0.5792	0.4196
0.8025	0.1975	0.7081	0.5946	0.4210
0.8985	0.1015	0.6972	0.6116	0.4264

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Toluene (1) + Ethylbenzene (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.8666	0.6766	0.5864
0.0000	1.0000	0.8671	0.7786	0.6751
0.1070	0.8930	0.8671	0.7642	0.6627
0.1909	0.8091	0.8671	0.7588	0.6579
0.3250	0.6750	0.8671	0.7473	0.6480
0.4008	0.5992	0.8671	0.7375	0.6395
0.5049	0.4951	0.8671	0.7320	0.6347
0.5996	0.4004	0.8671	0.7213	0.6254
0.6937	0.3063	0.8671	0.7154	0.6203
0.7804	0.2196	0.8671	0.7028	0.6094
0.9107	0.0893	0.8670	0.6892	0.5975

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Toluene (1) + Ethylbenzene (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.8623	0.6406	0.5524
0.0000	1.0000	0.8627	0.7335	0.6328
0.1070	0.8930	0.8627	0.7201	0.6212
0.1909	0.8091	0.8627	0.7144	0.6163
0.3250	0.6750	0.8626	0.7036	0.6069
0.4008	0.5992	0.8626	0.6953	0.5998
0.5049	0.4951	0.8626	0.6895	0.5948
0.5996	0.4004	0.8626	0.6790	0.5857
0.6937	0.3063	0.8625	0.6744	0.5817
0.7804	0.2196	0.8625	0.6627	0.5716
0.9107	0.0893	0.8623	0.6507	0.5611

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Toluene (1) + Ethylbenzene (2)

T = 308.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.8527	0.5756	0.4908
0.0000	1.0000	0.8536	0.6590	0.5625
0.1070	0.8930	0.8536	0.6480	0.5532
0.1909	0.8091	0.8536	0.6434	0.5492
0.3250	0.6750	0.8535	0.6330	0.5403
0.4008	0.5992	0.8534	0.6257	0.5340
0.5049	0.4951	0.8533	0.6209	0.5298
0.5996	0.4004	0.8532	0.6112	0.5215
0.6937	0.3063	0.8531	0.6018	0.5134
0.7804	0.2196	0.8531	0.5969	0.5093
0.9107	0.0893	0.8529	0.5854	0.4992

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Toluene (1) + Ethylbenzene (2)

T = 313.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.8483	0.5493	0.4660
0.0000	1.0000	0.8494	0.6281	0.5335
0.1070	0.8930	0.8494	0.6184	0.5252
0.1909	0.8091	0.8493	0.6134	0.5210
0.3250	0.6750	0.8492	0.6037	0.5127
0.4008	0.5992	0.8491	0.5969	0.5068
0.5049	0.4951	0.8490	0.5924	0.5029
0.5996	0.4004	0.8489	0.5831	0.4950
0.6937	0.3063	0.8488	0.5743	0.4875
0.7804	0.2196	0.8487	0.5695	0.4833
0.9107	0.0893	0.8484	0.5581	0.4735

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Hexane (1) + Cyclohexane (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.7787	1.2590	0.9804
0.1126	0.8874	0.7622	1.0324	0.7869
0.2022	0.7978	0.7500	0.9104	0.6828
0.3009	0.6991	0.7368	0.8051	0.5932
0.3947	0.6053	0.7253	0.7260	0.5265
0.5052	0.4948	0.7130	0.6660	0.4749
0.5873	0.4127	0.7023	0.6141	0.4313
0.6859	0.3141	0.6917	0.5703	0.3945
0.7929	0.2071	0.6803	0.5286	0.3596
0.8868	0.1132	0.6706	0.5012	0.3361

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Hexane (1) + Cyclohexane (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.7740	1.1599	0.8978
0.1126	0.8874	0.7575	0.9575	0.7253
0.2022	0.7978	0.7454	0.8490	0.6329
0.3009	0.6991	0.7322	0.7547	0.5526
0.3947	0.6053	0.7208	0.6849	0.4937
0.5052	0.4948	0.7085	0.6305	0.4467
0.5873	0.4127	0.6978	0.5827	0.4066
0.6859	0.3141	0.6871	0.5424	0.3727
0.7929	0.2071	0.6758	0.5041	0.3406
0.8868	0.1132	0.6661	0.4793	0.3193

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Hexane (1) + Ethylbenzene (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.8671	0.7786	0.6751
0.1088	0.8912	0.8434	0.7148	0.6028
0.1967	0.8033	0.8246	0.6747	0.5564
0.2875	0.7125	0.8053	0.6376	0.5134
0.3813	0.6187	0.7856	0.6022	0.4731
0.5119	0.4881	0.7583	0.5634	0.4272
0.5788	0.4212	0.7445	0.5466	0.4069
0.6760	0.3240	0.7246	0.5221	0.3783
0.7691	0.2309	0.7057	0.5038	0.3555
0.8733	0.1267	0.6847	0.4877	0.3339

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Hexane (1) + Ethylbenzene (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.8627	0.7335	0.6328
0.1088	0.8912	0.8390	0.6754	0.5666
0.1967	0.8033	0.8202	0.6380	0.5233
0.2875	0.7125	0.8009	0.6045	0.4841
0.3813	0.6187	0.7812	0.5728	0.4475
0.5119	0.4881	0.7539	0.5361	0.4042
0.5788	0.4212	0.7401	0.5213	0.3858
0.6760	0.3240	0.7201	0.4987	0.3591
0.7691	0.2309	0.7012	0.4807	0.3371
0.8733	0.1267	0.6802	0.4669	0.3176

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Hexane (1) + Octane (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.7025	0.7738	0.5436
0.0797	0.9203	0.6998	0.7464	0.5223
0.1847	0.8153	0.6961	0.7103	0.4944
0.3236	0.6764	0.6909	0.6669	0.4608
0.3833	0.6167	0.6885	0.6470	0.4454
0.4937	0.5063	0.6840	0.6126	0.4190
0.5902	0.4098	0.6798	0.5864	0.3986
0.7091	0.2909	0.6743	0.5487	0.3700
0.8072	0.1928	0.6696	0.5211	0.3489
0.8919	0.1081	0.6653	0.5012	0.3335

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Hexane (1) + Octane (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.6985	0.7303	0.5101
0.0797	0.9203	0.6958	0.7046	0.4903
0.1847	0.8153	0.6920	0.6727	0.4655
0.3236	0.6764	0.6867	0.6329	0.4346
0.3833	0.6167	0.6844	0.6145	0.4206
0.4937	0.5063	0.6798	0.5823	0.3958
0.5902	0.4098	0.6755	0.5581	0.3770
0.7091	0.2909	0.6700	0.5236	0.3508
0.8072	0.1928	0.6652	0.4970	0.3306
0.8919	0.1081	0.6609	0.4813	0.3181

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Hexane (1) + Toluene (2)

T = 293.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.8666	0.6766	0.5864
0.1231	0.8769	0.8365	0.6228	0.5210
0.2051	0.7949	0.8172	0.5936	0.4851
0.2926	0.7074	0.7973	0.5673	0.4523
0.4090	0.5910	0.7719	0.5368	0.4143
0.5008	0.4992	0.7526	0.5186	0.3903
0.5721	0.4279	0.7382	0.5082	0.3751
0.6772	0.3228	0.7176	0.4924	0.3533
0.7849	0.2151	0.6974	0.4813	0.3357
0.8945	0.1055	0.6777	0.4744	0.3215

Table 4.8 (Cont'd): Densities and Viscosities of the Binary System: Hexane (1) + Toluene (2)

T = 298.15 K

X_1	X_2	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.8623	0.6406	0.5524
0.1231	0.8769	0.8319	0.5904	0.4912
0.2051	0.7949	0.8125	0.5669	0.4606
0.2926	0.7074	0.7927	0.5396	0.4278
0.4090	0.5910	0.7673	0.5113	0.3923
0.5008	0.4992	0.7481	0.4937	0.3694
0.5721	0.4279	0.7336	0.4852	0.3559
0.6772	0.3228	0.7131	0.4708	0.3358
0.7849	0.2151	0.6928	0.4599	0.3186
0.8945	0.1055	0.6732	0.4552	0.3064

Table 4.9: Densities and Viscosities of the Ternary System: Hexane (1) + Ethylbenzene (2) + Octane (3)

T = 293.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.0000	0.8671	0.7786	0.6751
0.0000	0.0000	1.0000	0.7025	0.7738	0.5436
0.7961	0.1167	0.0872	0.6926	0.5488	0.3801
0.0629	0.8697	0.0675	0.7192	0.6550	0.4711
0.0761	0.1000	0.8239	0.7435	0.6016	0.4473
0.3194	0.3708	0.3099	0.7110	0.5881	0.4182
0.5560	0.2783	0.1657	0.6911	0.5199	0.3593
0.2226	0.6207	0.1567	0.7838	0.6850	0.5369
0.2217	0.1918	0.5865	0.7377	0.6004	0.4429
0.4398	0.4005	0.1597	0.7269	0.5341	0.3883

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Ethylbenzene (2) + Octane (3)

T = 298.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.0000	0.8627	0.7335	0.6328
0.0000	0.0000	1.0000	0.6985	0.7303	0.5101
0.7961	0.1167	0.0872	0.6882	0.5233	0.3601
0.0629	0.8697	0.0675	0.7149	0.6214	0.4442
0.0761	0.1000	0.8239	0.7392	0.5726	0.4233
0.3194	0.3708	0.3099	0.7067	0.5603	0.3959
0.5560	0.2783	0.1657	0.6866	0.4960	0.3406
0.2226	0.6207	0.1567	0.7796	0.6495	0.5063
0.2217	0.1918	0.5865	0.7334	0.5715	0.4192
0.4398	0.4005	0.1597	0.7225	0.5092	0.3679

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Toluene (2) + Octane (3)

T = 293.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.0000	0.8666	0.6766	0.5864
0.0000	0.0000	1.0000	0.7025	0.7738	0.5436
0.7636	0.1325	0.1039	0.6876	0.5042	0.3467
0.1037	0.8041	0.0922	0.8201	0.6267	0.5139
0.1369	0.1599	0.7032	0.7158	0.6926	0.4957
0.3365	0.3921	0.2714	0.7403	0.5830	0.4316
0.4555	0.3154	0.2290	0.7250	0.5599	0.4059
0.2626	0.5096	0.2278	0.7611	0.5941	0.4521
0.2741	0.3455	0.3804	0.7358	0.6099	0.4487
0.2471	0.3924	0.3605	0.7431	0.6123	0.4550

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Toluene (2) + Octane (3)

T = 298.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.0000	0.8623	0.6406	0.5524
0.0000	0.0000	1.0000	0.6985	0.7303	0.5101
0.7636	0.1325	0.1039	0.6831	0.4819	0.3292
0.1037	0.8041	0.0922	0.8155	0.5939	0.4843
0.1369	0.1599	0.7032	0.7116	0.6559	0.4667
0.3365	0.3921	0.2714	0.7360	0.5544	0.4080
0.4555	0.3154	0.2290	0.7206	0.5320	0.3834
0.2626	0.5096	0.2278	0.7567	0.5635	0.4264
0.2741	0.3455	0.3804	0.7314	0.5848	0.4277
0.2471	0.3924	0.3605	0.7388	0.5814	0.4295

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Cyclohexane (2) + Octane (3)

T = 293.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.0000	0.7787	1.2590	0.9804
0.0000	0.0000	1.0000	0.7025	0.7738	0.5436
0.7541	0.1473	0.0987	0.6792	0.5400	0.3667
0.1037	0.8076	0.0887	0.7536	0.9701	0.7311
0.1258	0.1631	0.7112	0.7062	0.7529	0.5317
0.3322	0.3969	0.2709	0.7121	0.7065	0.5031
0.3075	0.5536	0.1390	0.7243	0.7526	0.5451
0.4629	0.3917	0.1453	0.7066	0.6583	0.4651
0.1737	0.4159	0.4104	0.7192	0.7742	0.5568
0.3470	0.2382	0.4148	0.7019	0.6808	0.4779

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Cyclohexane (2) + Octane (3)

T = 298.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.0000	0.7740	1.1599	0.8978
0.0000	0.0000	1.0000	0.6985	0.7303	0.5101
0.7541	0.1473	0.0987	0.6747	0.5151	0.3476
0.1037	0.8076	0.0887	0.7491	0.9046	0.6777
0.1258	0.1631	0.7112	0.7020	0.7112	0.4993
0.3322	0.3969	0.2709	0.7078	0.6689	0.4734
0.3075	0.5536	0.1390	0.7198	0.7095	0.5107
0.4629	0.3917	0.1453	0.7021	0.6235	0.4378
0.1737	0.4159	0.4104	0.7150	0.7307	0.5225
0.3470	0.2382	0.4148	0.6977	0.6451	0.4501

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Cyclohexane (2) + Ethylbenzene (3)

T = 293.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.0000	0.7787	1.2590	0.9804
0.0000	0.0000	1.0000	0.8671	0.7786	0.6751
0.7961	0.1167	0.0872	0.6889	0.5136	0.3538
0.0629	0.8697	0.0675	0.7749	1.0343	0.8015
0.0761	0.1000	0.8239	0.8414	0.7386	0.6214
0.3194	0.3708	0.3099	0.7637	0.6699	0.5116
0.5560	0.2783	0.1657	0.7223	0.5874	0.4242
0.2226	0.6207	0.1567	0.7613	0.7871	0.5992
0.2217	0.1918	0.5865	0.8022	0.6746	0.5412
0.4398	0.4005	0.1597	0.7350	0.6425	0.4722

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Cyclohexane (2) + Ethylbenzene (3)

T = 298.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.0000	0.7740	1.1599	0.8978
0.0000	0.0000	1.0000	0.8627	0.7335	0.6328
0.7961	0.1167	0.0872	0.6844	0.4902	0.3355
0.0629	0.8697	0.0675	0.7703	0.9569	0.7371
0.0761	0.1000	0.8239	0.8370	0.6966	0.5831
0.3194	0.3708	0.3099	0.7592	0.6349	0.4820
0.5560	0.2783	0.1657	0.7178	0.5580	0.4005
0.2226	0.6207	0.1567	0.7567	0.7412	0.5608
0.2217	0.1918	0.5865	0.7978	0.6395	0.5102
0.4398	0.4005	0.1597	0.7305	0.6090	0.4449

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Cyclohexane (2) + Toluene (3)

T = 293.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.0000	0.7787	1.2590	0.9804
0.0000	0.0000	1.0000	0.8666	0.6766	0.5864
0.8289	0.1023	0.0688	0.6834	0.4994	0.3413
0.0813	0.8608	0.0579	0.7709	1.0079	0.7770
0.0767	0.0839	0.8394	0.8392	0.6524	0.5475
0.3041	0.3615	0.3344	0.7625	0.6357	0.4847
0.5408	0.2809	0.1784	0.7213	0.5729	0.4133
0.2158	0.6179	0.1663	0.7603	0.7686	0.5844
0.2307	0.1800	0.5893	0.7943	0.6097	0.4843
0.4290	0.3963	0.1746	0.7342	0.6253	0.4591

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Cyclohexane (2) + Toluene (3)

T = 298.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.0000	0.7740	1.1599	0.8978
0.0000	0.0000	1.0000	0.8623	0.6406	0.5524
0.8289	0.1023	0.0688	0.6789	0.4776	0.3243
0.0813	0.8608	0.0579	0.7662	0.9387	0.7192
0.0767	0.0839	0.8394	0.8346	0.6175	0.5153
0.3041	0.3615	0.3344	0.7579	0.6022	0.4564
0.5408	0.2809	0.1784	0.7168	0.5437	0.3897
0.2158	0.6179	0.1663	0.7557	0.7217	0.5454
0.2307	0.1800	0.5893	0.7897	0.5791	0.4573
0.4290	0.3963	0.1746	0.7296	0.5926	0.4324

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Toluene (2) + Ethylbenzene (3)

T = 293.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6594	0.4683	0.3088
0.0000	1.0000	0.0000	0.8666	0.6766	0.5864
0.0000	0.0000	1.0000	0.8671	0.7786	0.6751
0.8534	0.0736	0.0730	0.6869	0.4825	0.3314
0.0764	0.8601	0.0636	0.8480	0.6551	0.5555
0.0939	0.0778	0.8283	0.8465	0.7179	0.6077
0.3176	0.3729	0.3095	0.7953	0.5895	0.4689
0.5802	0.2540	0.1658	0.7398	0.5219	0.3861
0.2101	0.6382	0.1517	0.8173	0.6088	0.4975
0.2024	0.1905	0.6071	0.8223	0.6521	0.5362
0.4368	0.4014	0.1618	0.7670	0.5452	0.4181

Table 4.9 (Cont'd): Densities and Viscosities of the Ternary System: Hexane (1) + Toluene (2) + Ethylbenzene (3)

T = 298.15 K

X_1	X_2	X_3	Density (kg/L)	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity $\times 10^3$ (Pa.s)
1.0000	0.0000	0.0000	0.6549	0.4488	0.2939
0.0000	1.0000	0.0000	0.8623	0.6406	0.5524
0.0000	0.0000	1.0000	0.8627	0.7335	0.6328
0.8534	0.0736	0.0730	0.6824	0.4611	0.3147
0.0764	0.8601	0.0636	0.8434	0.6138	0.5176
0.0939	0.0778	0.8283	0.8420	0.6771	0.5702
0.3176	0.3729	0.3095	0.7908	0.5605	0.4433
0.5802	0.2540	0.1658	0.7352	0.4973	0.3656
0.2101	0.6382	0.1517	0.8127	0.5775	0.4693
0.2024	0.1905	0.6071	0.8178	0.5715	0.4673
0.4368	0.4014	0.1618	0.7625	0.5189	0.3956

4.6 Testing the Predictive Capabilities of the Viscosity Models

The experimental data reported earlier in this chapter were employed to critically test the predictive capabilities of the literature viscosity models; namely, the predictive version of McAllister three-body model, the pseudo-binary McAllister model, the GC-UNIMOD, the generalized corresponding states principle (GCSP), and the Allan and Teja correlation. The models were used to predict the viscosities of the systems measured in the present study and the predicted viscosities were compared with the corresponding experimental viscosities measured in the present study. The calculations were performed by means of a computer package developed by Nhaesi (1998).

For the purpose of comparison, the percent absolute average deviation (%AAD) was used as a criterion to compare the predicted and experimental viscosity values over the entire composition range at every temperature level employed. The %AAD is given by

$$\%AAD = \frac{1}{m}\left[\sum_{i=1}^{m}\frac{\left|\nu_i^{exp} - \nu_i^{pred}\right|}{\nu_i^{exp}}\right]\times 100 \qquad (4.1)$$

where m is the number of experimental data points and ν is the experimental or predicted kinematic viscosity.

In addition, the percent maximum deviation of the model from experimental data (%MAX) was also reported, where the %MAX is given by

$$\%MAX = \max\left[\frac{v_i^{exp} - v_i^{pred}}{v_i^{exp}}\right]\times 100 \qquad (4.2)$$

A brief discussion of the performance of every model is presented in separate sections followed by an overall comparison.

4.6.1 The predictive version of McAllister three-body interaction model

As discussed earlier in Chapter 2, Nhaesi and Asfour (2000a) developed the generalized McAllister three-body model for multi-component liquid systems. The model they developed is given by

$$\ell n v_m = \sum_{i=1}^{n} x_i^3 \ell n(v_i M_i) + 3\sum_{\substack{i=1 \\ i\neq j}}^{n}\sum_{j=1}^{n} x_i^2 x_j \ell n(v_{ij} M_{ij}) + 6\sum_{\substack{i=1 \\ i\neq j\neq k}}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n} x_i^2 x_j x_k \ell n(v_{ijk} M_{ijk}) - \ell n(M_{avg}) \qquad (4.3)$$

When equation (4.3) is written for binary and ternary systems, the following expressions are obtained

(i) For the binary systems

$$\ell n v = x_1^3 \ell n v_1 + 3x_1^2 x_2 \ell n v_{12} + 3x_1 x_2^2 \ell n v_{21} + x_2^3 \ell n v_2 - \ell n[x_1 + x_2 M_2/M_1] + 3x_1^2 x_2 \ell n[(2 + M_2/M_1)/3] + 3x_1 x_2^2 \ell n[(1 + 2M_2/M_1)/3] + x_2^3 \ell n[M_2/M_1] \qquad (4.4)$$

(ii) For the ternary systems

$$\begin{aligned}\ell n\nu = {} & x_1^3\ell n\nu_1 + x_2^3\ell n\nu_2 + x_3^3\ell n\nu_3 + 3x_1^2x_2\ell n\nu_{12} + 3x_1^2x_3\ell n\nu_{13} + 3x_2^2x_1\ell n\nu_{21} \\ & + 3x_2^2x_3\ell n\nu_{23} + 3x_3^2x_1\ell n\nu_{31} + 3x_3^2x_2\ell n\nu_{32} + 6x_1x_2x_3\ell n\nu_{123} \\ & - \ell n(x_1M_1 + x_2M_2 + x_3M_3) + x_1^3\ell nM_1 + x_2^3\ell nM_2 + x_3^3\ell nM_3 \\ & + 3x_1^2x_2\ell n\left(\frac{2M_1 + M_2}{3}\right) + 3x_1^2x_3\ell n\left(\frac{2M_1 + M_3}{3}\right) \\ & + 3x_2^2x_1\ell n\left(\frac{2M_2 + M_2}{3}\right) + 3x_2^2x_3\ell n\left(\frac{2M_2 + M_3}{3}\right) \\ & + 3x_3^2x_1\ell n\left(\frac{2M_3 + M_1}{3}\right) + 3x_3^2x_2\ell n\left(\frac{2M_3 + M_2}{3}\right) \\ & + 6x_1x_2x_3\ell n\left(\frac{M_1 + M_2 + M_3}{3}\right)\end{aligned} \tag{4.5}$$

Equation (4.4) contains two binary parameters whereas equation (4.5) contains six binary interaction parameters and one ternary interaction parameter. In order to estimate these parameters, the following equations are used for *n*-alkanes and regular systems:

For n-alkanes (Asfour *et al.* 1991)

$$\frac{\nu_{ij}}{\left(\nu_i^2\nu_j\right)^{1/3}} = 1 + 0.044\frac{\left(N_j - N_i\right)^2}{\left(N_i^2\ N_j\right)^{1/3}} \tag{4.6}$$

where $i < j$

For Regular systems (Nhaesi and Asfour 1998)

$$\frac{\nu_{ij}}{\left(\nu_i^2\nu_j\right)^{1/3}} = 0.8735 + 0.0715\frac{\left(ECN_j - ECN_i\right)^2}{\left(ECN_i^2 ECN_j\right)^{1/3}} \tag{4.7}$$

where $i < j$

and in general for both systems, the other binary parameters can be estimated from the following equation (Asfour *et al.* 1991):

$$\nu_{ji} = \nu_{ij}\left(\frac{\nu_j}{\nu_i}\right)^{1/3} \tag{4.8}$$

For the ternary parameters (Nhaesi and Asfour 2000a)

$$\frac{\nu_{123}}{(\nu_1\nu_2\nu_3)^{1/3}} = 0.9637 + 0.0313\frac{(ECN_3 - ECN_1)^2}{ECN_2} \tag{4.9}$$

With the help of equations (4.6) through (4.8) for calculating the binary parameters and equation (4.9) for calculating the ternary parameter(s), and by using equation (4.4) in case of *n*-alkanes systems, or equation (4.5) in case of regular solutions one can obtain the viscosity of the mixture at any given composition. It should also be pointed out here that in case of regular systems, equations (4.6), (4.7), and (4.9) require the knowledge of the effective carbon number. The effective carbon number can be calculated as suggested by Nhaesi and Asfour (1998) from the following equation

$$\ell n(\nu) = -1.943 + 0.193(ECN) \tag{4.10}$$

where ν is the kinematic viscosity of the pure component, whose effective carbon number is to be determined, at 308.15 K. The estimated effective carbon numbers of the components involved in composing the systems investigated in this study are listed in Table (4.10).

The experimental data for the binary and ternary systems reported earlier were used to test the predictive capability of the McAllister model. The results are reported in

Table 4.10: ECN of Pure Compounds as Calculated by Equation (4.10)

Pure Compound	ECN
Hexane	6.0
Heptane	7.0
Octane	8.0
Ethylbenzene	7.9
Cyclohexane	10.01
Toluene	7.2

Tables (4.11) through (4.13). For the binary sub-systems of the quinary system (heptane + octane + cyclohexane + toluene + ethylbenzene), the overall %AAD is 1.91% and the maximum deviation is 3.89%. For the binary systems of hexane-containing mixtures, the overall %AAD is 1.40% and the maximum deviation is 2.83%. Finally, the results for ternary systems showed an overall %AAD of 2.86% and a maximum deviation of 6.58%. This indicates that the McAllister model predicted the viscosities of those systems well.

It should be pointed out here that in our calculations, only the systems heptane (1) + octane (2), toluene (1) + ethylbenzene (2), and hexane (1) + octane (2) were considered *n*-alkane systems, whereas the remaining systems were considered regular solutions. For the system toluene (1) + ethylbenzene (2), it was found that the use of equation (4.6) gave much better results than when equation (4.7) was employed. This is not surprising since toluene consists of a benzene ring with a CH_3 group attached to it, whereas ethylbenzene consists of a benzene ring with a CH_2CH_3 group attached to it. Therefore, it is reasonable to assume that in such a case the actual interactions take place between those side chains which are of the n-alkane type (Al-Gherwi *et al.* 2005). In addition, it was found that equation (4.10) overpredicted the effective carbon number of cyclohexane. When a cyclohexane effective carbon number value (ECN) of 10.01 was used, as suggested by Nhaesi and Asfour (1998), an AAD value of 4.88 resulted. However, when an ECN of 7.5 [a value representing 75% of the value calculated from equation (4.10)] was used, the %AAD dropped to 2.40. The same kind of behavior was reported by El-Hadad (2004) and by Cai (2004). The overprediction of the effective carbon number value may be attributed to the unique shape and size of the cyclohexane molecule. Thus 75% of the

value obtained on the basis of the equation proposed by Nhaesi and Asfour (1998), appears to give much better predictions (Al-Gherwi *et al.* 2005).

Table (4.14) shows the %AADs in case of systems containing cyclohexane when an effective carbon number of 10.01 was employed and when 75 % of that value was used.

Table 4.11: Results of Testing the McAllister Three-Body Model by using the Experimental Data of the binary sub-systems of the quinary system: Heptane + Octane + Cyclohexane + Toluene + Ethylbenzene

System	Temperature, K	%AAD	%MAX
Cyclohexane (1) + Ethylbenzene (2)	293.15	4.00	7.90
	298.15	3.58	6.93
	308.15	2.35	5.02
	313.15	1.92	4.25
Cyclohexane (1) + Toluene (2)	293.15	4.06	7.67
	298.15	3.77	6.88
	308.15	2.50	5.02
	313.15	2.03	4.43
Heptane (1) + Cyclohexane (2)	293.15	2.55	5.96
	298.15	1.89	5.13
	308.15	1.53	3.81
	313.15	1.34	3.34
Heptane (1) + Ethylbenzene (2)	293.15	1.40	2.64
	298.15	1.71	3.00
	308.15	2.15	3.45
	313.15	2.25	3.68
Heptane (1) + Octane (2)	293.15	0.32	0.96
	298.15	0.23	0.61
	308.15	0.18	0.51
	313.15	0.17	0.45
Heptane (1) + Toluene (2)	293.15	1.07	2.52
	298.15	1.19	2.53
	308.15	1.75	3.25
	313.15	1.82	3.43

Table 4.11 (Cont'd) : Results of Testing the McAllister Three-Body Model by using the Experimental Data of the Binary Sub-systems of the quinary system: Heptane + Octane + Cyclohexane + Toluene + Ethylbenzene

System	Temperature, K	%AAD	%MAX
Octane (1) + Cyclohexane (2)	293.15	2.43	6.55
	298.15	1.79	5.00
	308.15	1.31	3.10
	313.15	1.30	2.52
Octane (1) + Ethylbenzene (2)	293.15	1.97	3.65
	298.15	2.00	3.63
	308.15	2.56	4.43
	313.15	2.78	4.90
Octane (1) + Toluene (2)	293.15	1.89	3.74
	298.15	1.96	3.57
	308.15	2.63	4.74
	313.15	2.77	4.97
Toluene (1) + Ethylbenzene (2)	293.15	0.43	1.18
	298.15	0.29	0.90
	308.15	0.30	0.76
	313.15	0.30	0.80

Table 4.12: Results of Testing the McAllister Three-Body Model by using the Experimental Data of the Binary Systems of Hexane with Octane, Cyclohexane, Toluene, and Ethylbenzene

System	Temperature, K	%AAD	%MAX
Hexane (1) + Cyclohexane (2)	293.15	4.65	8.69
	298.15	4.23	7.94
Hexane (1) + Ethylbenzene (2)	293.15	0.43	0.93
	298.15	0.53	1.17
Hexane (1) + Octane (2)	293.15	0.19	0.75
	298.15	0.23	1.11
Hexane (1) + Toluene (2)	293.15	0.41	0.97
	298.15	0.53	1.11

Table 4.13: Results of Testing the McAllister Three-Body Model by using the Experimental Data of the Ternary Systems of Hexane with Octane, Cyclohexane, Toluene, and Ethylbenzene

System	Temperature, K	%AAD	%MAX
Hexane (1) + Ethylbenzene (2) + Octane (3)	293.15	2.16	4.58
	298.15	2.30	4.70
Hexane (1) + Toluene (2) + Octane (3)	293.15	1.73	4.29
	298.15	1.84	4.38
Hexane (1) + Cyclohexane (2) + Octane(3)	293.15	2.77	6.68
	298.15	2.47	5.88
Hexane (1) + Cyclohexane (2) +	293.15	4.72	10.37
Ethylbenzene(3)	298.15	4.28	9.33
Hexane (1) + Cyclohexane (2) +	293.15	4.82	10.47
Toluene (3)	298.15	4.42	9.80
Hexane (1) + Toluene (2) +	293.15	1.35	3.24
Ethylbenzene (3)	298.15	1.51	5.28

Table 4.14: The Effect of Cyclohexane Effective Carbon Number on the Predictive Capability of the McAllister Model

System	Temperature, K	Cyclohexane ECN = 10.01		Cyclohexane ECN = 7.5	
		%AAD	%MAX	%AAD	%MAX
Cyclohexane (1) +	293.15	5.80	10.49	4.00	7.90
Ethylbenzene (2)	298.15	5.37	9.49	3.58	6.93
	308.15	4.11	7.54	2.35	5.02
	313.15	3.67	6.72	1.92	4.25
Cyclohexane (1) +	293.15	7.33	12.42	4.06	7.67
Toluene (2)	298.15	7.03	11.87	3.77	6.88
	308.15	5.71	9.66	2.50	5.02
	313.15	5.13	9.17	2.03	4.43
Heptane (1) +	293.15	6.70	11.97	2.55	5.96
Cyclohexane (2)	298.15	5.77	9.34	1.89	5.13
	308.15	5.50	9.43	1.53	3.81
	313.15	5.13	8.75	1.34	3.34
Octane (1) +	293.15	3.96	8.85	2.43	6.55
Cyclohexane (2)	298.15	3.09	7.27	1.79	5.00
	308.15	2.04	5.33	1.31	3.10
	313.15	1.74	4.73	1.30	2.52

4.6.2 The *Pseudo-Binary* McAllister Model

Nhaesi and Asfour (2000b) incorporated the *pseudo-binary* model which was developed earlier by Wu and Asfour (1992) into the predictive version of McAllister model for multi-component systems, which was developed by Nhaesi and Asfour (2000a). The idea of doing this is to reduce both the complexity of the calculations involved and the time required for calculations since the *pseudo-binary* model reduces the number of components in a system to two no matter how many components are involved in constituting a system. This is performed by arbitrarily selecting one of the components as component 1 and the rest of the other components are lumped together and treated as *pseudo*-component 2'. The properties of the *pseudo*-component 2' are given as follows:

The ECN of the *pseudo*-component 2'

$$(\mathrm{ECN})_{2'} = \sum_{i=2}^{n} X_i (\mathrm{ECN})_i \tag{4.11}$$

The viscosity of the *pseudo*-component 2'

$$\ell n \nu_{2'} = \sum_{i=2}^{n} X_i \ell n \nu_i \tag{4.12}$$

and the molecular weight of the *pseudo*-component 2'

$$\ell n M_{2'} = \sum_{i=2}^{n} X_i \ell n M_i \tag{4.13}$$

Nhaesi and Asfour (2000b) reported that the mole fraction X_i used in equations (2.11), (2.12), and (2.13) was normalized according to the following formula

$$X_i = \frac{x_i}{\sum_{i=2}^{n} x_i} \tag{4.14}$$

It should be pointed out here that the six ternary hexane-containing systems investigated in this study were considered as regular solutions. Therefore, equation (4.7) for regular systems was employed to estimate the binary interaction parameters along with equation (4.8). In order to estimate the value of the kinematic viscosity of the mixture, the obtained interaction parameters were substituted into the McAllister model, equation (4.4), with the help of equations (4.11), (4.12), and (4.13).

Table (4.15) gives the results of testing the pseudo-binary McAllister model. The experimental data of the ternary systems were used to test the model.

The pseudo-binary McAllister model showed an overall %AAD of 3.18% and a maximum deviation from the experimental data of 7.22%. The generalized McAllister three-body model predicted the experimental data slightly better than the pseudo-binary McAllister model. However, the pseudo-binary McAllister model is simpler and takes less time for calculation than the generalized McAllister model.

Table 4.15: Results of Testing the Pseudo-Binary McAllister Model by using the Experimental Data of the Ternary Systems of Hexane with Octane, Cyclohexane, Toluene, and Ethylbenzene

System	Temperature, K	%AAD	%MAX
Hexane (1) + Ethylbenzene (2) + Octane (3)	293.15	1.85	4.85
	298.15	1.91	4.88
Hexane (1) + Toluene (2) + Octane (3)	293.15	1.03	3.00
	298.15	1.15	3.04
Hexane (1) + Cyclohexane (2) + Octane(3)	293.15	3.72	8.93
	298.15	3.29	8.29
Hexane (1) + Cyclohexane (2) +	293.15	5.89	12.76
Ethylbenzene(3)	298.15	5.44	11.69
Hexane (1) + Cyclohexane (2) +	293.15	5.91	12.90
Toluene (3)	298.15	5.51	12.23
Hexane (1) + Toluene (2) +	293.15	1.47	2.16
Ethylbenzene (3)	298.15	1.04	3.90

4.6.3 The Generalized Corresponding States Principle (GCSP)

Teja and Rice (1981) reported the generalized corresponding states principle for the prediction of the viscosities of multi-component liquid mixtures. As presented earlier in Chapter 2, the GCSP model requires the knowledge of the critical properties of the components constituting a mixture and selection of two reference fluids. The critical properties of compounds are obtained from many references such as Poling *et al.* (2001). One of the main disadvantages of this model is the fact that there are no criteria of selecting the two reference fluids. While there is no problem encountered in selecting the reference fluids in case of binary systems, problems arise in case of multi-component systems. For example, in case of ternary systems, one has to make all possible selections ternary systems, perform all required calculations, and the one that gave the lowest %AAD is selected. Tables (4.16) through (4.18) report the results of testing the GCSP model by using the experimental data of binary and ternary systems.

Table 4.16: Results of testing the GCSP Model by using the Experimental Data of the binary sub-systems of the quinary system: Heptane + Octane + Cyclohexane + Toluene + Ethylbenzene

System	Temperature, K	%AAD	%MAX
Cyclohexane (1) + Ethylbenzene (2)	293.15	12.81	17.54
	298.15	12.27	16.72
	308.15	10.69	14.61
	313.15	10.14	13.88
Cyclohexane (1) + Toluene (2)	293.15	13.35	18.36
	298.15	12.99	17.81
	308.15	11.32	15.29
	313.15	10.59	15.00
Heptane (1) + Cyclohexane (2)	293.15	9.85	13.91
	298.15	8.79	13.16
	308.15	8.55	11.82
	313.15	8.13	11.07
Heptane (1) + Ethylbenzene (2)	293.15	5.53	7.73
	298.15	5.12	7.04
	308.15	4.56	6.43
	313.15	4.43	6.08
Heptane (1) + Octane (2)	293.15	0.36	0.84
	298.15	0.28	0.75
	308.15	0.25	0.56
	313.15	0.25	0.49
Heptane (1) + Toluene (2)	293.15	6.02	8.12
	298.15	5.90	7.99
	308.15	5.19	7.07
	313.15	5.10	6.90

Table 4.16 (Cont'd): Results of Testing the GCSP Model by using the Experimental Data of the Binary Sub-systems of the quinary system: Heptane + Octane + Cyclohexane + Toluene + Ethylbenzene

System	Temperature, K	%AAD	%MAX
Octane (1) + Cyclohexane (2)	293.15	10.03	14.93
	298.15	8.98	13.30
	308.15	7.75	11.42
	313.15	7.33	10.84
Octane (1) + Ethylbenzene (2)	293.15	5.47	7.62
	298.15	5.47	7.47
	308.15	4.73	6.62
	313.15	4.44	6.24
Octane (1) + Toluene (2)	293.15	6.04	8.32
	298.15	5.97	8.31
	308.15	5.09	7.22
	313.15	4.89	6.92
Toluene (1) + Ethylbenzene (2)	293.15	0.49	1.12
	298.15	0.32	0.82
	308.15	0.32	0.69
	313.15	0.31	0.73

Table 4.17: Results of Testing the GCSP Model by using the Experimental Data of the Binary Systems of Hexane with Octane, Cyclohexane, Toluene, and Ethylbenzene

System	Temperature, K	%AAD	%MAX
Hexane (1) + Cyclohexane (2)	293.15	11.13	15.85
	298.15	10.63	14.97
Hexane (1) + Ethylbenzene (2)	293.15	4.88	6.39
	298.15	4.73	6.24
Hexane (1) + Octane (2)	293.15	0.49	0.95
	298.15	0.53	1.34
Hexane (1) + Toluene (2)	293.15	6.11	8.30
	298.15	6.00	8.39

Table 4.18: Results of Testing the GCSP Model by using the Experimental Data of the Ternary Systems of Hexane with Octane, Cyclohexane, Toluene, and Ethylbenzene

System	Temperature, K	%AAD	%MAX
Hexane (1) + Ethylbenzene (2) + Octane (3)	293.15	11.42	23.02
	298.15	11.22	22.66
Hexane (1) + Toluene (2) + Octane (3)	293.15	15.69	36.01
	298.15	15.37	35.19
Hexane (1) + Cyclohexane (2) + Octane(3)	293.15	29.22	69.78
	298.15	28.64	68.54
Hexane (1) + Cyclohexane (2) +	293.15	10.24	36.77
Ethylbenzene(3)	298.15	10.03	36.02
Hexane (1) + Cyclohexane (2) +	293.15	12.82	18.16
Toluene (3)	298.15	12.11	17.39
Hexane (1) + Toluene (2) +	293.15	12.83	39.26
Ethylbenzene (3)	298.15	11.68	38.38

For the binary sub-systems of the quinary system: heptane + octane + cyclohexane + toluene + ethylbenzene, the overall AAD is 6.3% and the maximum deviation is 8.8%. For the binary systems of the hexane-containing mixtures, the overall AAD is 5.6% and the maximum deviation is 7.80%. Finally, for the ternary systems an overall AAD of 15.1% and a maximum deviation of 36.8% were obtained. This shows clearly that the relatively poor predictive capability of the GCSP when compared with that of the generalized McAllister model.

4.6.4 The GC-UNIMOD Model

Cao *et al.* (1993) developed a model, on the basis of statistical thermodynamics, for predicting the viscosities of multi-component liquid mixtures as well as for predicting vapor-liquid-equilibrium (VLE). The model is called the GC-UNIMOD model. They used an extensive database consisting of data on binary, ternary and some quaternary liquid mixtures to test their viscosity prediction model. Their results of testing the model indicated a good predictive capability.

The GC-UNIMOD model, as was presented earlier in Chapter 2, has two parts; *viz.*, a combinatorial part and residual part. This is given by the following equation:

$$\ell n(\nu) = \sum_{i=1}^{n} \left[\zeta_i^C + \zeta_i^R \right] \tag{4.15}$$

where ξ_i^C and ξ_i^R are the combinatorial part and residual part, respectively. It should be pointed out here that the parameters used in the GC-UNIMOD are same as those in the UNIFAC model for VLE.

It was reported by Nhaesi (1998) that the residual part has insignificant effect on the predictive capability of the model. Same conclusions were made by El-Hadad (2004) and Cai (2004). In this study, the model was applied (i) taking into consideration the two parts, and (ii) considering only the combinatorial part, in other words, setting the residual part in equation (4.15) to zero; i.e., $\xi_i^R = 0$.

Tables (4.19) through (4.21) report the results of testing the GC-UNIMOD model by using the experimental data obtained in the present study. When the results are examined, it is clear that the residual part has an insignificant effect on the performance of the GC-UNIMOD. This supports the findings of Nhaesi (1998), El-Hadad (2004), and Cai (2004). In addition, the GC-UNIMOD gave relatively high %AADs when compared with the generalized McAllister model and the *pseudo-binary* McAllister model.

4.6.5 The Allan and Teja Correlation

Allan and Teja (1991) proposed an Antoine-type equation, equation (2.77), for predicting the viscosities of liquid mixtures. The equation was presented in detail in Chapter 2. The results of testing the Allan and Teja correlation are reported in Tables (4.22) through (4.24). The results indicated that the Allan and Teja correlation has a lower predictive capability than the generalized McAllister model and the *pseudo-binary* McAllister model.

Table 4.19: Results of Testing the GC-UNIMOD Model by using the Experimental Data of the binary sub-systems of the quinary system: Heptane + Octane + Cyclohexane + Toluene + Ethylbenzene

		$\xi_i^R \neq 0$		$\xi_i^R = 0$	
System	**Temperature, K**	**%AAD**	**%MAX**	**%AAD**	**%MAX**
Cyclohexane (1) +	293.15	11.54	15.72	12.91	17.66
Ethylbenzene (2)	298.15	10.89	14.70	12.27	16.69
	308.15	9.15	12.41	10.49	14.32
	313.15	8.54	11.63	9.87	13.50
Cyclohexane (1) +	293.15	13.37	17.87	14.49	19.85
Toluene (2)	298.15	12.79	17.07	13.91	19.02
	308.15	10.81	14.25	11.90	16.11
	313.15	9.95	13.75	11.04	15.58
Heptane (1) +	293.15	11.23	15.53	11.23	15.53
Cyclohexane (2)	298.15	10.07	14.86	10.07	14.86
	308.15	9.64	13.26	9.64	13.26
	313.15	9.15	12.41	9.15	12.41
Heptane (1) +	293.15	3.24	4.71	4.54	6.40
Ethylbenzene (2)	298.15	2.87	4.07	4.16	5.74
	308.15	2.34	3.51	3.62	5.16
	313.15	2.24	3.21	3.51	4.85
Heptane (1) +	293.15	0.43	1.15	0.43	1.15
Octane (2)	298.15	0.32	0.76	0.32	0.76
	308.15	0.25	0.65	0.25	0.65
	313.15	0.21	0.58	0.21	0.58

Table 4.19 (Cont'd) : Results of Testing the GC-UNIMOD Model by using the Experimental Data of the Binary Sub-systems of the quinary system: Heptane + Octane + Cyclohexane + Toluene + Ethylbenzene

		$\xi_i^R \neq 0$		$\xi_i^R = 0$	
System	**Temperature, K**	**%AAD**	**%MAX**	**%AAD**	**%MAX**
Heptane (1) +	293.15	3.06	4.10	4.02	5.44
Toluene (2)	298.15	2.94	3.96	3.90	5.24
	308.15	2.29	3.09	3.25	4.41
	313.15	2.21	2.99	3.18	4.33
Octane (1) +	293.15	5.99	9.76	5.99	9.76
Cyclohexane (2)	298.15	5.09	8.37	5.09	8.37
	308.15	4.13	6.84	4.13	6.84
	313.15	3.81	6.40	3.81	6.40
Octane (1) +	293.15	3.01	4.22	4.26	5.98
Ethylbenzene (2)	298.15	2.99	4.06	4.24	5.81
	308.15	2.29	3.25	3.52	4.97
	313.15	2.02	2.92	3.24	4.62
Octane (1) +	293.15	3.23	4.28	4.20	5.78
Toluene (2)	298.15	3.12	4.21	4.09	5.72
	308.15	2.28	3.17	3.24	4.66
	313.15	2.08	2.88	3.05	4.37
Toluene (1) +	293.15	0.46	1.06	0.84	1.52
Ethylbenzene (2)	298.15	0.99	1.54	0.31	0.80
	308.15	0.83	1.28	0.29	0.66
	313.15	0.76	1.19	0.29	0.70

Table 4.20: Results of Testing the GC-UNIMOD Model by using the Experimental Data of the Binary Systems of Hexane with Octane, Cyclohexane, Toluene, and Ethylbenzene

		$\xi_i^R \neq 0$		$\xi_i^R = 0$	
System	**Temperature, K**	**%AAD**	**%MAX**	**%AAD**	**%MAX**
Hexane (1) +	293.15	9.89	14.18	9.89	14.18
Cyclohexane (2)	298.15	9.43	13.37	9.43	13.37
Hexane (1) +	293.15	3.57	4.77	4.85	6.35
Ethylbenzene (2)	298.15	3.42	4.44	4.70	6.21
Hexane (1) +	293.15	0.63	0.98	0.63	0.98
Octane (2)	298.15	0.63	0.93	0.63	0.93
Hexane (1) +	293.15	3.71	4.97	4.66	6.34
Toluene (2)	298.15	3.59	4.89	4.55	6.45

Table 4.21: Results of Testing the GC-UNIMOD Model by using the Experimental Data of the Ternary Systems of Hexane with Octane, Cyclohexane, Toluene, and Ethylbenzene

		$\xi_i^R \neq 0$		$\xi_i^R = 0$	
System	**Temperature, K**	**%AAD**	**%MAX**	**%AAD**	**%MAX**
Hexane (1) + Ethylbenzene (2)	293.15	4.59	5.73	4.66	5.81
+ Octane (3)	298.15	4.35	5.46	4.41	5.47
Hexane (1) + Toluene (2) +	293.15	4.62	5.70	4.74	5.84
Octane (3)	298.15	4.42	5.55	4.54	5.69
Hexane (1) + Cyclohexane (2)	293.15	7.72	11.35	7.72	11.35
+ Octane(3)	298.15	7.18	10.66	7.18	10.66
Hexane (1) + Cyclohexane (2)	293.15	10.49	14.99	11.68	16.25
+ Ethylbenzene(3)	298.15	9.95	14.02	11.13	15.25
Hexane (1) + Cyclohexane (2)	293.15	11.32	15.97	12.34	17.25
+ Toluene (3)	298.15	10.82	15.36	11.83	16.62
Hexane (1) + Toluene (2) +	293.15	4.08	6.41	4.14	6.63
Ethylbenzene (3)	298.15	5.11	12.87	5.18	12.95

Table 4.22: Results of Testing the Allan and Teja Correlation by using the Experimental Data of the binary sub-systems of the quinary system: Heptane + Octane + Cyclohexane + Toluene + Ethylbenzene

System	Temperature, K	%AAD	%MAX
Cyclohexane (1) + Ethylbenzene (2)	293.15	30.62	51.16
	298.15	29.73	49.63
	308.15	28.55	46.66
	313.15	28.22	45.56
Cyclohexane (1) + Toluene (2)	293.15	31.72	51.16
	298.15	30.77	49.63
	308.15	29.31	46.66
	313.15	28.96	45.56
Heptane (1) + Cyclohexane (2)	293.15	21.41	51.15
	298.15	20.86	49.62
	308.15	19.04	46.66
	313.15	18.58	45.56
Heptane (1) + Ethylbenzene (2)	293.15	6.68	21.16
	298.15	6.70	20.77
	308.15	6.77	20.43
	313.15	6.93	20.50
Heptane (1) + Octane (2)	293.15	1.06	1.97
	298.15	0.66	1.22
	308.15	0.46	0.97
	313.15	1.15	1.60
Heptane (1) + Toluene (2)	293.15	4.41	6.49
	298.15	4.40	6.57
	308.15	4.10	6.26
	313.15	4.00	6.50

Table 4.22 (Cont'd): Results of Testing the Allan and Teja Correlation by using the Experimental Data of the Binary Sub-systems of the quinary system: Heptane + Octane + Cyclohexane + Toluene + Ethylbenzene

System	Temperature, K	%AAD	%MAX
Octane (1) + Cyclohexane (2)	293.15	21.67	51.16
	298.15	21.15	49.63
	308.15	19.90	46.66
	313.15	19.51	45.56
Octane (1) + Ethylbenzene (2)	293.15	6.73	21.11
	298.15	6.46	20.77
	308.15	6.74	20.43
	313.15	6.93	20.50
Octane (1) + Toluene (2)	293.15	7.96	24.16
	298.15	7.77	23.84
	308.15	7.74	22.84
	313.15	7.80	22.68
Toluene (1) + Ethylbenzene (2)	293.15	22.99	24.37
	298.15	22.49	23.84
	308.15	21.88	23.00
	313.15	21.84	22.78

Table 4.23: Results of Testing the Allan and Teja Correlation by using the Experimental Data of the Binary Systems of Hexane with Octane, Cyclohexane, Toluene, and Ethylbenzene

System	Temperature, K	%AAD	%MAX
Hexane (1) + Cyclohexane (2)	293.15	20.72	51.16
	298.15	19.90	49.63
Hexane (1) + Ethylbenzene (2)	293.15	7.36	21.16
	298.15	7.27	20.77
Hexane (1) + Octane (2)	293.15	0.54	1.94
	298.15	0.67	2.17
Hexane (1) + Toluene (2)	293.15	7.82	24.16
	298.15	7.71	23.84

Table 4.24: Results of Testing the Allan and Teja Correlation by using the Experimental Data of the Ternary Systems of Hexane with Octane, Cyclohexane, Toluene, and Ethylbenzene

System	Temperature, K	%AAD	%MAX
Hexane (1) + Ethylbenzene (2) + Octane (3)	293.15	3.39	21.16
	298.15	3.40	20.77
Hexane (1) + Toluene (2) + Octane (3)	293.15	5.11	24.16
	298.15	5.04	23.84
Hexane (1) + Cyclohexane (2) + Octane(3)	293.15	16.04	51.16
	298.15	15.48	49.63
Hexane (1) + Cyclohexane (2) +	293.15	19.13	51.16
Ethylbenzene(3)	298.15	18.55	49.63
Hexane (1) + Cyclohexane (2) +	293.15	19.43	51.16
Toluene (3)	298.15	18.82	49.63
Hexane (1) + Toluene (2) +	293.15	12.18	24.16
Ethylbenzene (3)	298.15	11.30	23.84

4.7 Overall Comparison of the Predictive Capabilities of the Models

Figures (4.1), (4.2), and (4.3) represent an overall comparison of the previously reported results of testing the predictive capabilities of the viscosity models considered in this study.

Figure (4.1) shows the comparison of the predictive capabilities of the viscosity models for the binary-subsystems of the quinary system: heptane, octane, cyclohexane, toluene, and ethylbenzene over the entire composition range at temperatures 293.15, 298.15, 308.15, and 313.15 K. It is clear that the generalized McAllister three-body model showed the lowest overall AAD of 1.8%. The Allan and Teja correlation gave the highest AAD of 15.7%.

Figure (4.2) reports the results of testing the models by using data on the binary hexane-containing systems over the entire composition range and temperatures 293.15 and 298.15 K. Again, the generalized McAllister three-body model showed the lowest AAD of 1.40%, whereas the Allan and Teja gave the highest AAD of 9%.

Finally, Figure (4.3) shows the results of testing the models for the case of the ternary systems at 293.15 and 298.15 K. Again, the generalized McAllister three-body model gave the lowest AAD of 2.9% followed by the pseudo-binary McAllister model which gave an AAD of 3.18%. The generalized corresponding states gave the highest AAD of 15.1%.

The generalized McAllister model as well as the pseudo-binary McAllister model showed the best predictive capability over the other models when the data of all the systems reported in this study are employed.

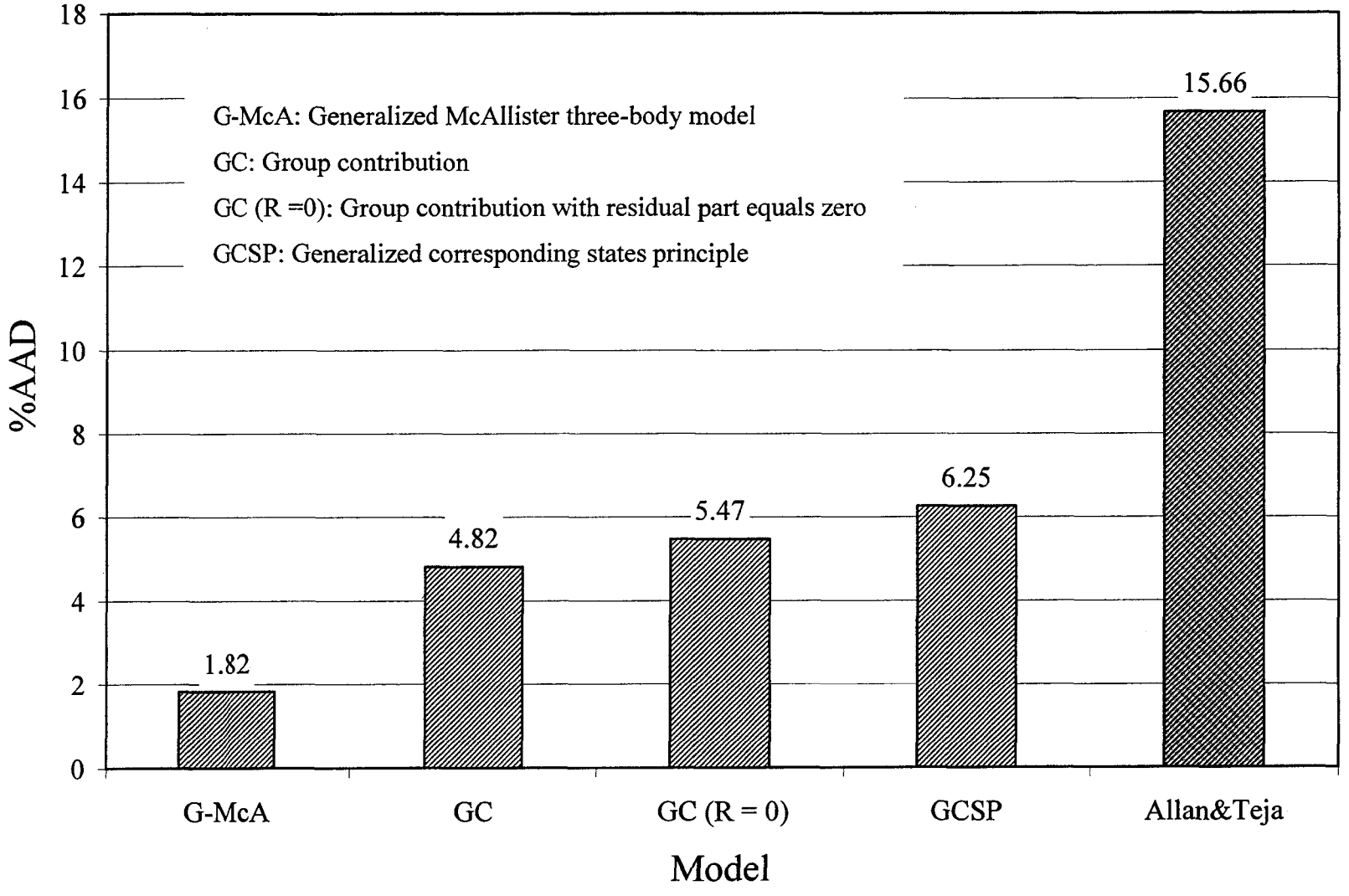

Figure 4.1: Overall model Comparison for the binary sub-systems of the quinary system:

Heptane (1) + Octane (2) + Cyclohexane (3) + Toluene (4) + Ethylbenzene (5)

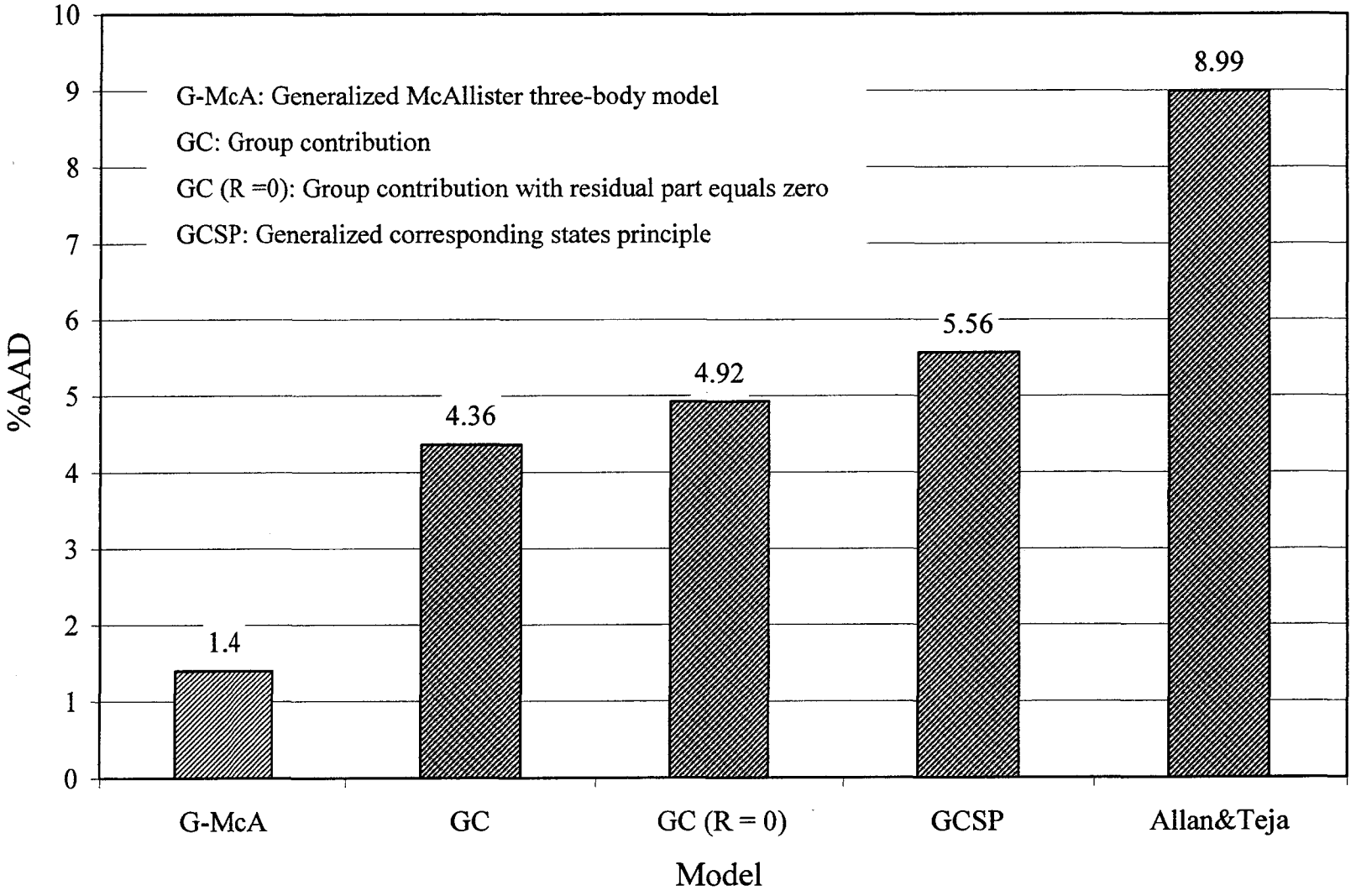

Figure 4.2: Overall model Comparison for the binary hexane-containing systems

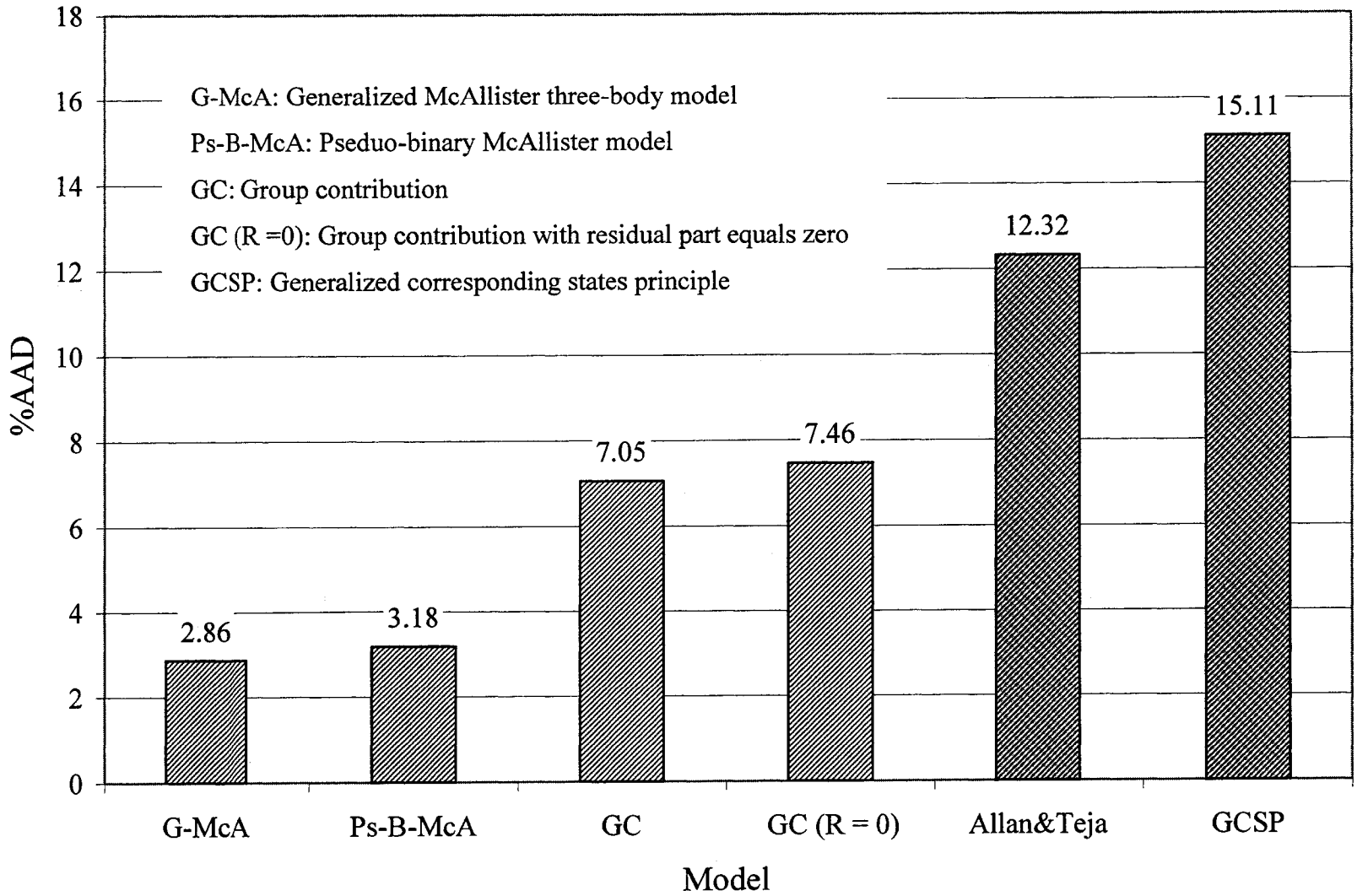

Figure 4.3: Overall model Comparison for the ternary systems

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The viscosities and densities of

(i) ten binary subsystems of the quinary system: heptane, octane, cyclohexane, toluene and ethylbenzene, were measured and reported at 293.15, 298.15, 308.15 and 313.15 K,

(ii) four binary subsystems of the quinary system: hexane, octane, cyclohexane, toluene, ethylbenzene, were measured and reported at 293.15, and 298.15 K, and

(iii) six ternary subsystems of the quinary system: hexane, octane, cyclohexane, toluene, ethylbenzene were measured and reported at 293.15 and 298.15 K.

were measured.

The viscosities and densities of the pure compounds constituting the investigated systems were measured at the indicated temperatures and were found to be in excellent agreement with their corresponding values available from the literature.

The experimental data were used to test the predictive capabilities of selected viscosity models from the literature; namely, the generalized McAllister three-body model, the *pseudo-binary* McAllister model, the GC-UNIMOD, the generalized

corresponding states principle (GCSP), and the Allan and Teja correlation. Of all the models, the overall predictive capability of the generalized McAllister model was far superior to the predictive capabilities of all other models.

In case of the ternary systems the *pseudo-binary* McAllister model ranked second with close %AADs.

It was found that the Nhaesi and Asfour (1998) equation, equation (4.41), for calculating the effective carbon number (ECN) of cyclohexane tends to overpredict the ECN. A value of ECN for cyclohexane that is 75% of that calculated from the Nhaesi and Asfour (1998) equation gave much better predicted viscosity values. This is consistent with earlier reports by El-Hadad (2004), Cai (2004), and Al-Gherwi *et al.* (2005).

It was also found that in case of systems containing toluene and ethylbenzene, while they are considered as regular systems, the use of the equation for calculating the McAllister adjustable parameter ν_{12}, equation (2.26), for *n*-alkane systems gave better predictions than equation (2.32) for regular solutions. This is not surprising since the toluene molecule consists of a benzene ring with a CH_3 group attached to it and the ethylbenzene molecule consists of a benzene ring with a CH_2-CH_3 group attached to it. It is therefore plausible to presume that the side chains, which are in reality straight chain hydrocarbons, play the major role here and simultaneously the presence of the benzene rings in the two molecules offsets their effects (Al-Gherwi *et al.* 2005).

The GC-UNIMOD ranked third with relatively high AADs. It was found that the residual part did not significantly improve the predictive capability of the model, which is consistent with the findings of earlier investigators; viz., Nhaesi (1998), El-Hadad (2004), and Cai (2004).

The Allan and Teja correlation exhibited the highest AADs in the binary systems whereas the GCSP showed the highest AAD in case of the ternary systems.

5.2 Recommendations

In light of the foregoing conclusions, the following recommendations are made:

i) The generalized McAllister model, while it gave much better predictions than other models available from the literature, it should be subjected to more testing by using multi-component regular solution data.

ii) Equation (4.10) was found to overestimate the value of the ECN of cyclohexane. This should be further investigated. Other cyclic compounds, e.g. systems containing cyclopentane should be studied

iii) A technique to use the generalized McAllister model in predicting associated solutions viscosities should be developed.

NOMENCLATURE

a	group interaction energy parameter
B	constant generally used as parameter
C	constant generally used as parameter
D	constant generally used as parameter
E	constant generally used as parameter
h	Plank's constant
i	index number
j	index number
k	index number
k	Boltzman's constant
M	molecular weight, g/mol
n	number of components of the mixture, number of interaction parameters
N	Avogadro's number
P	pressure, atm
q	area parameter of molecule
R	gas constant
r	rate at which a molecule moving under shear stress
r_o	rate at which a molecule moving as a result of thermal fluctuation
t	efflux time of the viscometer, s
T	temperature, K
V	molar volume of the liquid, L/kmol
X	mole fraction

Z	compressibility factor

Greek Letters

η	absolute viscosity, Pa.s
θ	shape factor
λ	center to center distance between a molecule and a hole in Eyring's theory
$\lambda_1, \lambda_2, \lambda_3$	intermolecular distance involved in Eyring's theory
ν	kinematic viscosity, m^2/s
ν_k^i	number of groups k in molecule
ν_{12}	McAllister three-body model binary interaction parameter
ν_{21}	McAllister three-body model binary interaction parameter
ν_{123}	McAllister three-body model ternary interaction parameter
ν_{1112}	McAllister four-body model interaction parameter
ν_{2111}	McAllister four-body model interaction parameter
ξ_{ij}	binary interaction parameter in the GCSP
ξ_{loc}	ξ based on local composition
ξ_i^c	pure component ξ value
ρ	density, kg/L
τ	oscillation period for the density meter, s
ϕ	shape factor, volume fraction
ϕ_{ji}	local volume fraction of component j around central molecule i
ω	Pitzer acentric factor

Ξ_{ki}	group property in GC-UNIMOD model
Ψ_{ki}	group residual viscosity in the GC-UNIMO model

Subscripts

1,2,3	refer to various components in the mixture, respectively
123	refer to interaction between three molecules
c	critical properties
i,j	refer to ith and jth component in the mixture
ij	refer to interaction of type i-j
ijk	refer to interaction of type i-j-k
n	refers to nth component of the mixture
r1	refers to reference fluid 1
r2	refers to reference fluid 2

Acronyms

AAD	average absolute deviation, %
ECN	effective carbon number
GC-UNIMOD	group contribution-viscosity thermodynamics model
MAX	maximum deviation, %
GCSP	generalized corresponding states principle
TRAPP	transport properties prediction

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APPENDICES

Appendix A

Raw Data of Viscosity and Density Measurements

Table A.1: Raw Data for the Binary System: Cyclohexane (1) + Ethylbenzene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1165	0.8835	25B350	0.731500	448.51	0.730449	421.25
0.1927	0.8073	25B366	0.730226	414.21	0.729170	391.20
0.2965	0.7035	25B365	0.728503	435.52	0.727441	410.97
0.4034	0.5966	25B350	0.726719	467.37	0.725654	440.53
0.5021	0.4979	25B366	0.725075	444.63	0.724001	418.51
0.5952	0.4048	25B365	0.723535	479.19	0.722453	450.40
0.6964	0.3036	25B350	0.721864	530.86	0.720775	498.25
0.7876	0.2124	25B366	0.720382	522.51	0.719282	488.59
0.9118	0.0882	25B365	0.718411	611.91	0.717302	567.85

Table A.1 (Cont'd): Raw Data for the Binary System: Cyclohexane (1) + Ethylbenzene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.1165	0.8835	25B350	0.728345	379.41	0.727294	360.98
0.1927	0.8073	25B366	0.727060	352.70	0.726004	334.85
0.2965	0.7035	25B365	0.725318	369.49	0.724255	351.27
0.4034	0.5966	25B350	0.723517	395.55	0.722447	375.78
0.5021	0.4979	25B366	0.721853	374.82	0.720778	355.47
0.5952	0.4048	25B365	0.720290	401.64	0.719207	380.25
0.6964	0.3036	25B350	0.718594	441.49	0.717500	417.3
0.7876	0.2124	25B366	0.717084	430.21	0.715982	405.14
0.9118	0.0882	25B365	0.715074	493.66	0.713959	462.49

Table A.2: Raw Data for the Binary System: Cyclohexane (1) + Toluene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.0960	0.9040	25B350	0.731547	394.40	0.730452	372.93
0.1961	0.8039	25B366	0.729698	370.29	0.728601	350.14
0.2952	0.7048	25B365	0.727909	393.60	0.726810	372.10
0.3960	0.6040	25B350	0.726143	427.43	0.725043	402.87
0.4872	0.5128	25B366	0.724604	410.62	0.723499	386.24
0.5916	0.4084	25B365	0.722900	451.69	0.721792	424.34
0.6896	0.3104	25B350	0.721375	507.74	0.720265	476.56
0.7886	0.2114	25B366	0.718800	509.58	0.716567	476.37
0.8968	0.1032	25B365	0.718402	595.40	0.717288	553.20

Table A.2 (Cont'd): Raw Data for the Binary System: Cyclohexane (1) + Toluene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.0960	0.9040	25B350	0.728261	336.02	0.727163	320.05
0.1961	0.8039	25B366	0.726404	315.28	0.725303	303.57
0.2952	0.7048	25B365	0.724610	334.72	0.723510	322.54
0.3960	0.6040	25B350	0.722835	361.91	0.721730	343.91
0.4872	0.5128	25B366	0.721286	346.3	0.720176	328.68
0.5916	0.4084	25B365	0.719575	379.88	0.718463	358.25
0.6896	0.3104	25B350	0.718041	422.2	0.716926	398.56
0.7886	0.2114	25B366	0.716567	419.3	0.715448	394.64
0.8968	0.1032	25B365	0.715050	481.48	0.713929	451.07

Table A.3: Raw Data for the Binary System: Heptane (1) + Cyclohexane (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1008	0.8992	25B350	0.704891	620.95	0.703799	601.20
0.2140	0.7860	25B366	0.702322	518.17	0.701243	495.30
0.3027	0.6973	25B365	0.700499	460.3	0.699430	433.00
0.3915	0.6085	25B350	0.698814	463.36	0.697749	435.83
0.4864	0.5136	25B366	0.697125	438.54	0.696066	413.28
0.5875	0.4125	25B365	0.695454	396.15	0.694400	372.74
0.6977	0.3023	25B350	0.693750	365.58	0.692703	341.92
0.7813	0.2187	25B366	0.692535	375.15	0.691492	357.00
0.9063	0.0937	25B365	0.690832	353.14	0.689794	340.20

Table A.3 (Cont'd): Raw Data for the Binary System: Heptane (1) + Cyclohexane (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.1008	0.8992	25B350	0.701607	503.02	0.700507	471.48
0.2140	0.7860	25B366	0.699077	427.73	0.697989	403.21
0.3027	0.6973	25B365	0.697279	384.71	0.696200	363.75
0.3915	0.6085	25B350	0.695614	388.18	0.694540	368.07
0.4864	0.5136	25B366	0.693946	370.77	0.692880	352.29
0.5875	0.4125	25B365	0.692289	335.68	0.691230	319.84
0.6977	0.3023	25B350	0.690603	308.78	0.689548	294.5
0.7813	0.2187	25B366	0.689399	323.8	0.688355	309.19
0.9063	0.0937	25B365	0.687712	306.32	0.686664	292.96

Table A.4: Raw Data for the Binary System: Heptane (1) + Ethylbenzene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1151	0.8849	25B350	0.728851	417.75	0.727803	396.68
0.2217	0.7783	25B366	0.725371	370.67	0.724328	351.94
0.2997	0.7003	25B365	0.721866	369.77	0.720819	351.74
0.3878	0.6122	25B350	0.718790	375.5	0.717745	358.2
0.4805	0.5195	25B366	0.715593	337.5	0.714525	322.36
0.5896	0.4104	25B365	0.711904	342.28	0.710859	326.36
0.6895	0.3105	25B350	0.708673	352.84	0.707626	336.55
0.7993	0.2007	25B366	0.705229	320.8	0.704184	306.36
0.8731	0.1269	25B365	0.702977	330.67	0.701931	315.57

Table A.4 (Cont'd): Raw Data for the Binary System: Heptane (1) + Ethylbenzene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.1151	0.8849	25B350	0.725710	358.52	0.724664	341.67
0.2217	0.7783	25B366	0.722235	318.97	0.721188	304.19
0.2997	0.7003	25B365	0.718727	319.13	0.717678	304.87
0.3878	0.6122	25B350	0.715650	325.61	0.714601	311.34
0.4805	0.5195	25B366	0.712430	293.53	0.711378	280.67
0.5896	0.4104	25B365	0.708765	297.39	0.707715	284.73
0.6895	0.3105	25B350	0.705531	307.7	0.704477	293.92
0.7993	0.2007	25B366	0.702085	279.64	0.701030	267.69
0.8731	0.1269	25B365	0.699834	288.9	0.698782	275.78

Table A.5: Raw Data for the Binary System: Heptane (1) + Octane (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1141	0.8859	25B350	0.692780	426.84	0.691780	404.49
0.2198	0.7802	25B366	0.692441	420.65	0.691439	398.84
0.2916	0.7084	25B365	0.692200	408.37	0.691196	387.80
0.3867	0.6133	25B350	0.691887	402.67	0.690877	382.72
0.4751	0.5249	25B366	0.691573	378.18	0.690562	359.72
0.5820	0.4180	25B365	0.691209	355.74	0.690189	338.15
0.6794	0.3206	25B350	0.690851	372.12	0.689828	355.23
0.7798	0.2202	25B366	0.688148	335.28	0.687123	320.12
0.9042	0.0958	25B365	0.688534	337.85	0.687516	321.83

Table A.5 (Cont'd): Raw Data for the Binary System: Heptane (1) + Octane (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.1141	0.8859	25B350	0.689783	365.27	0.688779	347.99
0.2198	0.7802	25B366	0.689429	360.52	0.688418	343.64
0.2916	0.7084	25B365	0.689184	350.8	0.688170	334.57
0.3867	0.6133	25B350	0.688852	346.53	0.687835	330.68
0.4751	0.5249	25B366	0.688534	325.65	0.687516	310.65
0.5820	0.4180	25B365	0.688148	306.62	0.687123	292.84
0.6794	0.3206	25B350	0.687777	322.96	0.686745	308.74
0.7798	0.2202	25B366	0.687394	291.43	0.686361	278.73
0.9042	0.0958	25B365	0.687015	293.26	0.685972	280.58

Table A.6: Raw Data for the Binary System: Heptane (1) + Toluene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1031	0.8969	25B350	0.728759	371.12	0.727671	352.43
0.2160	0.7840	25B366	0.724048	328.49	0.722968	312.76
0.2980	0.7020	25B365	0.720829	334.05	0.719753	317.78
0.3860	0.6140	25B350	0.717580	344.73	0.716508	328.51
0.4821	0.5179	25B366	0.714210	313.8	0.713141	299.08
0.5864	0.4136	25B365	0.710801	323.43	0.709739	307.78
0.6952	0.3048	25B350	0.707466	336.91	0.706406	321.65
0.7831	0.2169	25B366	0.704932	311.5	0.703877	297.45
0.9064	0.0936	25B365	0.692110	325.21	0.691072	310.55

Table A.6 (Cont'd): Raw Data for the Binary System: Heptane (1) + Toluene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.1031	0.8969	25B350	0.725494	318.89	0.724402	304.36
0.2160	0.7840	25B366	0.720802	284.38	0.719718	271.29
0.2980	0.7020	25B365	0.717596	289.17	0.716514	276.43
0.3860	0.6140	25B350	0.714359	299.7	0.713277	286.1
0.4821	0.5179	25B366	0.711000	272.72	0.709925	261.02
0.5864	0.4136	25B365	0.707603	281.21	0.706532	269.36
0.6952	0.3048	25B350	0.704282	293.5	0.703215	281.17
0.7831	0.2169	25B366	0.701761	271.75	0.700696	260.11
0.9064	0.0936	25B365	0.688983	283.59	0.687934	271.57

Table A.7: Raw Data for the Binary System: Octane (1) + Cyclohexane (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.0847	0.9153	25B350	0.715099	640.03	0.714001	599.11
0.2029	0.7971	25B366	0.712723	531.64	0.711654	500.27
0.2843	0.7157	25B365	0.710963	515.97	0.709903	487.49
0.3956	0.6044	25B350	0.709546	516.45	0.708495	488.72
0.4963	0.5037	25B366	0.708136	458.55	0.707100	433.93
0.6017	0.3983	25B365	0.706795	458.55	0.705766	434.18
0.6782	0.3218	25B350	0.705911	472.68	0.704887	446.90
0.8081	0.1919	25B366	0.704534	421.73	0.703521	399.7
0.8992	0.1008	25B365	0.703649	428.83	0.702638	406.6

Table A.7 (Cont'd): Raw Data for the Binary System: Octane (1) + Cyclohexane (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.0847	0.9153	25B350	0.711800	522.29	0.710693	489.2
0.2029	0.7971	25B366	0.709497	441.05	0.708412	415.41
0.2843	0.7157	25B365	0.707780	432.53	0.706710	408.33
0.3956	0.6044	25B350	0.706393	435.34	0.705337	411.62
0.4963	0.5037	25B366	0.705018	387.48	0.703974	367.38
0.6017	0.3983	25B365	0.703705	388.79	0.702671	369.05
0.6782	0.3218	25B350	0.702840	400.9	0.701814	380.92
0.8081	0.1919	25B366	0.701488	359.69	0.700467	341.85
0.8992	0.1008	25B365	0.700618	366.2	0.699607	348.59

Table A.8: Raw Data for the Binary System: Octane (1) + Ethylbenzene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1005	0.8995	25B350	0.729415	432.50	0.728373	408.57
0.1909	0.8091	25B366	0.726050	395.00	0.725014	369.54
0.3003	0.6997	25B365	0.722223	399.75	0.721192	378.45
0.3947	0.6053	25B350	0.719129	416.45	0.718105	394.27
0.4910	0.5090	25B366	0.716139	383.63	0.715114	363.04
0.5964	0.4036	25B365	0.713051	398.75	0.712032	377.17
0.7047	0.2953	25B350	0.710056	421.06	0.709044	399.83
0.7846	0.2154	25B366	0.707973	390.66	0.706964	371.75
0.9086	0.0914	25B365	0.704893	414.98	0.703886	393.15

Table A.8 (Cont'd): Raw Data for the Binary System: Octane (1) + Ethylbenzene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.1005	0.8995	25B350	0.726288	369.30	0.725248	351.75
0.1909	0.8091	25B366	0.722939	337.10	0.721900	322.00
0.3003	0.6997	25B365	0.719128	343.20	0.718095	327.11
0.3947	0.6053	25B350	0.716048	357.63	0.715020	341.28
0.4910	0.5090	25B366	0.713066	329.60	0.712042	314.44
0.5964	0.4036	25B365	0.709996	342.72	0.708972	327.80
0.7047	0.2953	25B350	0.707015	362.04	0.705999	345.45
0.7846	0.2154	25B366	0.704937	336.30	0.703920	320.77
0.9086	0.0914	25B365	0.701873	355.07	0.700863	338.33

Table A.9: Raw Data for the Binary System: Octane (1) + Toluene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.0906	0.9094	25B350	0.729258	381.69	0.728169	362.35
0.1955	0.8045	25B366	0.724975	349.38	0.723904	331.71
0.3008	0.6992	25B365	0.721090	362.31	0.720030	344.38
0.3953	0.6047	25B350	0.717927	383.40	0.716878	363.47
0.4955	0.5045	25B366	0.714858	358.54	0.713815	339.25
0.5924	0.4076	25B365	0.712135	377.98	0.711101	357.62
0.6721	0.3279	25B350	0.710050	402.80	0.709023	383.02
0.8025	0.1975	25B366	0.706924	383.34	0.705909	364.36
0.8985	0.1015	25B365	0.704814	408.48	0.703802	387.35

Table A.9 (Cont'd): Raw Data for the Binary System: Octane (1) + Toluene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.0906	0.9094	25B350	0.726011	327.60	0.724925	312.20
0.1955	0.8045	25B366	0.721762	300.37	0.720691	286.69
0.3008	0.6992	25B365	0.717910	312.40	0.716844	298.25
0.3953	0.6047	25B350	0.714772	330.45	0.713715	315.55
0.4955	0.5045	25B366	0.711726	308.82	0.710681	294.83
0.5924	0.4076	25B365	0.709030	326.20	0.707990	311.50
0.6721	0.3279	25B350	0.706966	348.66	0.705934	332.77
0.8025	0.1975	25B366	0.703868	329.50	0.702846	314.28
0.8985	0.1015	25B365	0.701780	351.28	0.700763	334.70

Table A.10: Raw Data for the Binary System: Toluene (1) + Ethylbenzene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1070	0.8930	25B350	0.733395	438.94	0.732342	414.66
0.1909	0.8091	25B366	0.733399	400.57	0.732345	378.37
0.3250	0.6750	25B365	0.733398	408.10	0.732336	385.45
0.4008	0.5992	25B350	0.733401	423.63	0.732335	400.41
0.5049	0.4951	25B366	0.733400	386.50	0.732331	365.29
0.5996	0.4004	25B365	0.733393	393.98	0.732321	372.02
0.6937	0.3063	25B350	0.733389	411.00	0.732313	388.40
0.7804	0.2196	25B366	0.733386	371.17	0.732305	351.15
0.9107	0.0893	25B365	0.733371	376.54	0.732281	356.54

Table A.10 (Cont'd): Raw Data for the Binary System: Toluene (1) + Ethylbenzene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 308.15 K		Temperature = 313.15 K	
0.1070	0.8930	25B350	0.730239	373.23	0.729190	355.11
0.1909	0.8091	25B366	0.730234	340.80	0.729179	324.18
0.3250	0.6750	25B365	0.730219	347.18	0.729158	330.37
0.4008	0.5992	25B350	0.730209	360.36	0.729144	342.84
0.5049	0.4951	25B366	0.730194	328.91	0.729123	313.15
0.5996	0.4004	25B365	0.730175	335.20	0.729100	319.16
0.6937	0.3063	25B350	0.730155	346.6	0.729077	329.98
0.7804	0.2196	25B366	0.730141	316.25	0.729057	301.12
0.9107	0.0893	25B365	0.730104	321.04	0.729015	305.58

Table A.11: Raw Data for the Binary System: Hexane (1) + Cyclohexane (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1126	0.8874	25B350	0.713982	592.67	0.712872	551.26
0.2022	0.7978	25B366	0.711703	480.26	0.710598	449.37
0.3009	0.6991	25B365	0.709225	439.55	0.708122	413.4
0.3947	0.6053	25B350	0.707055	417.04	0.705955	394.42
0.5052	0.4948	25B366	0.704937	351.90	0.703838	334.20
0.5873	0.4127	25B365	0.702688	335.81	0.701589	319.38
0.6859	0.3141	25B350	0.700667	328.01	0.699567	312.49
0.7929	0.2071	25B366	0.698496	280.01	0.697394	267.85
0.8868	0.1132	25B365	0.696645	274.72	0.695543	262.92

Table A.12: Raw Data for the Binary System: Hexane (1) + Ethylbenzene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1088	0.8912	25B350	0.729054	410.63	0.728002	388.95
0.1967	0.8033	25B366	0.725589	356.47	0.724534	338.18
0.2875	0.7125	25B365	0.722029	348.52	0.720969	331.28
0.3813	0.6187	25B350	0.718363	346.23	0.717297	330.00
0.5119	0.4881	25B366	0.713268	298.16	0.712193	284.64
0.5788	0.4212	25B365	0.710670	299.22	0.709593	285.84
0.6760	0.3240	25B350	0.706912	300.46	0.705829	287.42
0.7691	0.2309	25B366	0.703332	267.06	0.702243	255.65
0.8733	0.1267	25B365	0.699336	267.45	0.698240	256.12

Table A.13: Raw Data for the Binary System: Hexane (1) + Octane (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.0797	0.9203	25B350	0.702221	428.73	0.701213	405.78
0.1847	0.8153	25B366	0.701511	375.10	0.700495	356.44
0.3236	0.6764	25B365	0.700517	364.44	0.699488	346.82
0.3833	0.6167	25B350	0.700070	371.83	0.699036	353.95
0.4937	0.5063	25B366	0.699201	323.88	0.698157	308.88
0.5902	0.4098	25B365	0.698398	320.79	0.697343	305.93
0.7091	0.2909	25B350	0.697354	315.68	0.696287	301.71
0.8072	0.1928	25B366	0.696445	276.06	0.695366	264.14
0.8919	0.1081	25B365	0.695624	274.73	0.694535	264.01

Table A.14: Raw Data for the Binary System: Hexane (1) + Toluene (2)

X_1	X_2	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
			Temperature = 293.15 K		Temperature = 298.15 K	
0.1231	0.8769	25B350	0.727788	358.02	0.726693	340.11
0.2051	0.7949	25B366	0.724217	313.98	0.723121	300.78
0.2926	0.7074	25B365	0.720530	310.44	0.719434	295.83
0.4090	0.5910	25B350	0.715805	308.85	0.714708	294.65
0.5008	0.4992	25B366	0.712197	274.80	0.711098	262.45
0.5721	0.4279	25B365	0.709483	278.48	0.708377	266.11
0.6772	0.3228	25B350	0.705593	283.53	0.704492	271.42
0.7849	0.2151	25B366	0.701752	255.37	0.700649	244.77
0.8945	0.1055	25B365	0.697998	260.26	0.696895	249.76

Table A.15: Raw Data for the Binary System: Hexane (1) + Ethylbenzene (2) + Octane (3)

X_1	X_2	X_3	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
				Temperature = 293.15 K		Temperature = 298.15 K	
0.7961	0.1167	0.0872	25B350	0.700840	315.71	0.699771	301.54
0.0629	0.8697	0.0675	25B366	0.705886	346.10	0.704852	329.43
0.0761	0.1000	0.8239	25B365	0.710478	329.02	0.709424	313.87
0.3194	0.3708	0.3099	25B350	0.704336	338.18	0.703281	322.78
0.5560	0.2783	0.1657	25B366	0.700550	275.44	0.699470	263.66
0.2226	0.6207	0.1567	25B365	0.718033	374.27	0.716995	355.87
0.2217	0.1918	0.5865	25B350	0.709393	345.20	0.708340	329.26
0.4398	0.4005	0.1597	25B366	0.707352	282.88	0.706273	270.52
0.7961	0.1167	0.0872	25B365	0.712029	353.00	0.710990	336.14

Table A.16: Raw Data for the Binary System: Hexane (1) + Toluene (2) + Octane (3)

X_1	X_2	X_3	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
				Temperature = 293.15 K		Temperature = 298.15 K	
0.7636	0.1325	0.1039	25B350	0.699888	290.28	0.698799	277.75
0.1037	0.8041	0.0922	25B366	0.724759	331.28	0.723675	314.96
0.1369	0.1599	0.7032	25B365	0.705243	378.36	0.704218	359.36
0.3365	0.3921	0.2714	25B350	0.709884	335.27	0.708820	319.39
0.4555	0.3154	0.2290	25B366	0.706997	296.31	0.705926	282.5
0.2626	0.5096	0.2278	25B365	0.713786	324.93	0.712717	308.88
0.2741	0.3455	0.3804	25B350	0.709024	350.61	0.707969	336.85
0.2471	0.3924	0.3605	25B366	0.710411	323.75	0.709355	308.41
0.7636	0.1325	0.1039	25B365	0.710244	309.61	0.709172	295.53

Table A.17: Raw Data for the Binary System: Hexane (1) + Cyclohexane (2) + Octane (3)

X_1	X_2	X_3	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
				Temperature = 293.15 K		Temperature = 298.15 K	
0.7541	0.1473	0.0987	25B350	0.698276	310.67	0.697187	296.86
0.1037	0.8076	0.0887	25B366	0.712385	511.68	0.711293	478.71
0.1258	0.1631	0.7112	25B365	0.703422	411.17	0.702401	389.62
0.3322	0.3969	0.2709	25B350	0.704557	405.91	0.703494	385.22
0.3075	0.5536	0.1390	25B366	0.706851	397.33	0.705771	375.81
0.4629	0.3917	0.1453	25B365	0.703498	359.76	0.702419	341.67
0.1737	0.4159	0.4104	25B350	0.705903	444.64	0.704853	420.79
0.3470	0.2382	0.4148	25B366	0.702621	359.67	0.701571	341.90
0.7541	0.1473	0.0987	25B365	0.707221	422.24	0.706146	399.76

Table A.18: Raw Data for the Binary System: Hexane (1) + Cyclohexane (2) + Ethylbenzene (3)

X_1	X_2	X_3	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
				Temperature = 293.15 K		Temperature = 298.15 K	
0.7961	0.1167	0.0872	25B350	0.700128	295.63	0.699033	282.51
0.0629	0.8697	0.0675	25B366	0.716368	545.44	0.715263	506.32
0.0761	0.1000	0.8239	25B365	0.728691	403.35	0.727638	381.64
0.3194	0.3708	0.3099	25B350	0.714263	384.97	0.713182	365.68
0.5560	0.2783	0.1657	25B366	0.706477	310.69	0.705387	296.12
0.2226	0.6207	0.1567	25B365	0.713821	429.76	0.712728	406.00
0.2217	0.1918	0.5865	25B350	0.721450	387.66	0.720384	368.33
0.4398	0.4005	0.1597	25B366	0.708876	339.54	0.707786	322.93
0.7961	0.1167	0.0872	25B365	0.716779	372.78	0.715704	353.88

Table A.19: Raw Data for the Binary System: Hexane (1) + Cyclohexane (2) + Toluene (3)

X_1	X_2	X_3	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
				Temperature = 293.15 K		Temperature = 298.15 K	
0.8289	0.1023	0.0688	25B350	0.699090	287.53	0.697989	275.32
0.0813	0.8608	0.0579	25B366	0.715611	531.57	0.714500	496.68
0.0767	0.0839	0.8394	25B365	0.728285	356.57	0.727190	338.37
0.3041	0.3615	0.3344	25B350	0.714039	365.35	0.712942	346.87
0.5408	0.2809	0.1784	25B366	0.706297	303.15	0.705197	288.64
0.2158	0.6179	0.1663	25B365	0.713633	419.68	0.712530	395.38
0.2307	0.1800	0.5893	25B350	0.719978	350.52	0.718881	333.58
0.4290	0.3963	0.1746	25B366	0.708721	330.55	0.707622	314.29
0.8289	0.1023	0.0688	25B365	0.717127	351.99	0.716029	334.32

Table A.20: Raw Data for the Binary System: Hexane (1) + Toluene (2) + Ethylbenzene (3)

X_1	X_2	X_3	Viscometer Number	Density Meter Reading	Efflux Time (s)	Density Meter Reading	Efflux Time (s)
				Temperature = 293.15 K		Temperature = 298.15 K	
0.8534	0.0736	0.0730	25B350	0.699765	277.89	0.698666	265.85
0.0764	0.8601	0.0636	25B366	0.729894	346.18	0.728803	325.42
0.0939	0.0778	0.8283	25B365	0.729615	392.13	0.728560	370.99
0.3176	0.3729	0.3095	25B350	0.720162	338.99	0.719083	322.92
0.5802	0.2540	0.1658	25B366	0.709778	276.48	0.708686	264.34
0.2101	0.6382	0.1517	25B365	0.724233	332.90	0.723145	316.51
0.2024	0.1905	0.6071	25B350	0.725161	374.74	0.724097	329.21
0.4368	0.4014	0.1618	25B366	0.714893	288.64	0.713805	275.60
0.8534	0.0736	0.0730	25B365	0.722873	339.8	0.721800	322.71

Appendix B

Estimated Experimental Errors

B.1 Density Measurements

The equation used with the density meter is:

$$\rho = \frac{A\tau^2}{1 - B\tau^2} - C \tag{B.1}$$

when equation (B.1) is differentiated with respect to the period of vibration, T, equation (B.2) is obtained.

$$d\rho = \frac{2A\tau}{\left(1 - B\tau^2\right)^2} d\tau \tag{B.2}$$

During the study, A DMA 602 density meter was used. The maximum fluctuation in density meter readings is 1×10^{-5} second.

For the DMA 602 measuring cell, the maximum value of τ was 0.731547 seconds at 293.15 K, substituting this value into equation (B.2) with the respected values for A, B and C, the maximum predicted error is calculated as:

$$d\rho = \frac{2(3.8828443)(0.731547)}{[1 + 0.0373463 \times (0.731547)^2]^2} \times 10^{-5} = 5.5 \times 10^{-5} \text{ kg/L}$$

B.2 Viscosity Measurement

From Chapter 3, the viscometer equation is:

$$v = Et - \frac{F}{t^2} \tag{B.3}$$

Differentiating equation (B.3) with respect to the efflux time, t, gives

$$dv = \left(E + \frac{F}{3t^3}\right) dt \tag{B.4}$$

For each system at each temperature, at least three measurements of efflux time were taken. The error in measuring the efflux time did not exceed $\pm 0.1\%$.

In order to calculate the maximum expected error in kinematic viscosity, dt can be assumed to be equal to 0.1% of the maximum efflux time measured by every viscometer.

Table B.1 shows the maximum predicted error in the kinematic viscosity for each viscometer used.

Table B.1: Estimated errors in measuring kinematic viscosity

Viscometer Number	Efflux Time (s)	dt (s)	$d\nu \times 10^{12}$ (m^2/s)
25B365	408.37	0.41	1.15
25B366	420.65	0.42	1.19
25B350	426.84	0.43	1.01

Example:

For viscometer 25B365

$$d\nu = \left(0.0018341 \times 10^{-9} + \frac{200.3167 \times 10^{-6}}{3 \times 408.37^3} \right) \times 0.41 = 1.15 \times 10^{-12} m^2 / s$$

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